

Phytoplankton and Zooplankton  
In Lakes Erie, Lake Huron and Lake Michigan: 1984

Volume 1 - Interpretive Report

by

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## Abstract

With the acknowledgement that biological monitoring was fundamental to charting ecosystem health (Great Lakes Water Quality Agreement 1978), EPA's program was developed for Lakes Erie, Huron and Michigan to: 1) monitor seasonal patterns, ranges of abundance and, in general, structure of the phytoplankton and zooplankton communities; 2) relate the biological components to variations in the physical, nutrient and biological environment; and 3) assess the annual variance to allow better long-term assessments of trophic structure and state. Several offshore stations (9-11) on several cruises (9-11) during the spring, summer and autumn of 1984 and winter of 1985 were sampled.

By examining changes in the phytoplankton and zooplankton in relation to water chemistry, evidence was found suggesting little change in the trophic status of Lakes Huron and Michigan while an improvement in the trophic status of Lake Erie was evident. The offshore region of Lake Michigan is experiencing changes in phytoplankton and zooplankton composition consistent with nutrient control and top-down control by fish. Even so, the biomass of phytoplankton and zooplankton and the trophic status of the lake have not changed significantly. The appearance and establishment of Daphnia pulicaria in offshore waters of Lake Huron suggest a change in the forage fish base. With the exception of the resurgence of Asterionella formosa in Lake Erie, plankton composition has changed little since the 60's. However, dramatic reductions in biomass of nuisance and eutrophic indicator species have occurred. These changes are consistent with expectations of long-term nutrient control. However, a change in piscivory is evident that has apparently allowed the establishment of the large cladoceran Daphnia pulicaria.

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## FOREWARD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago, to focus attention on the significant and complex natural resource represented by the Great Lakes.

GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by universities, private firms, State, Federal and Canadian Governmental Agencies and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. The Office also coordinates U.S. actions in fulfillment of the Great Lakes Water Quality Agreement of 1978 between Canada and the United States of America.

This report presents results of the phytoplankton and zooplankton portions of the water quality surveillance program conducted by GLNPO on Lakes Michigan, Huron and Erie in 1984 and in winter of 1985. Results of the physical and chemical portions of the surveillance program may be found in a companion report:

Lesht, Barry M. and David C. Rockwell. 1987. The State of the Middle Great Lakes: Results of the 1984 Water Quality Survey of Lakes Erie, Huron and Michigan. Publication Number ANL/ER-87-1. Argonne National Laboratory, Argonne, Illinois 60439.

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## OVERVIEW

With the acknowledgement that biological monitoring was fundamental to charting ecosystem health (Great Lakes Water Quality Agreement 1978), EPA's program was developed for Lakes Erie, Huron and Michigan to: 1) monitor seasonal patterns, ranges of abundance and structure of the phytoplankton and zooplankton communities; 2) relate the biological components to variations in the physical, nutrient and biological environment; and 3) assess the annual variance to allow better long-term assessments of trophic structure and state.

The program has proven successful. By examining changes in the phytoplankton and zooplankton in relation to water chemistry, evidence was found suggesting little change in the trophic status of Lakes Huron and Michigan while an improvement in the trophic status of Lake Erie was evident within the past ten years. The offshore region of Lake Michigan is experiencing changes in phytoplankton and zooplankton composition consistent with nutrient control and top-down control by fish. Even so, the biomass of phytoplankton and zooplankton and the trophic status of the lake have not changed significantly. The appearance and establishment of Daphnia pulicaria in offshore waters of Lake Huron suggest a change in the forage fish base. With the exception of the resurgence of Asterionella formosa in Lake Erie, plankton composition has changed little since the 60's. However, dramatic reductions in biomass of nuisance and eutrophic indicator species have occurred. These changes are consistent with expectations of long-term nutrient control. However, a change in piscivory is evident that has apparently allowed the establishment of the large cladoceran Daphnia pulicaria.

The following summaries for Lakes Michigan, Huron and Erie outline the major observations of the 1984 intensive sampling of the offshore region. As such, the 1983 (Makarewicz 1987) and 1984 studies provide a basis for long-term monitoring of the structure and functioning of the Great Lakes.

## SUMMARY

### Lake Michigan

1. In 1984, 327 algal and 52 zooplankton species were observed. Compared to 1983, a 15% and 24% reduction in the number of algal and zooplankton species were observed. As the same sampling, enumeration procedure and taxonomists were employed, the observed fluctuations in species composition are due to both natural and sampling variability of the plankton population.
2. Compared to Lake Huron, variability in common algal species in Lake Michigan in 1983 and 1984 was high. 76% of the common species observed in 1984 were also common species in 1983. 31% of the common species observed in 1983 were not common in 1984.
3. Average phytoplankton and zooplankton abundances were  $22,220 \pm 1400$  cells/mL and  $59,764 \pm 8,284$  organisms/m<sup>3</sup> for the study period. Mean algal and zooplankton biomass were  $0.55 \pm 0.038$  g/m<sup>3</sup> and  $33.2 \pm 4.9$  mg/m<sup>3</sup> for the study period.

4. As in Lakes Erie and Huron, diatoms possessed the greatest diversity of species (166) and biomass (70.0% of the total) in 1984. The Cryptophyta accounted for the second highest biomass in 1984.
5. Picoplankton represented 82.9% of the total abundance but only 1.4% of the algal biomass.
6. Diatoms were dominant throughout the study period, accounting for as much as 80% but never less than 55% of the phytoplankton biomass. The overwhelming dominance of the diatoms in 1984 precluded the prominent seasonal succession of algal divisions observed in 1983.
7. The large drop in diatom biomass observed in August of 1983 was not observed in 1984. A bloom of Rhizosolenia eriensis during 1984, not observed in 1983, was the major cause of the dominance of diatoms in August of 1984. A similar situation was observed in Lake Huron in 1984.
8. Abundance of phytoplankton decreased from the most northern station to Station 57 and remained the same southward to the most southerly station, where it increased slightly.
9. Vertical distribution studies indicated that an increase in abundance occurred and a 100%+ increase in species diversity occurred with depth at Station 47. The increase in abundance and diversity correlated with the decrease in temperature associated with the metalimnion.
10. Winter samples were analyzed in 1985. Algal biomass and abundance were low during the winter but were not significantly different from the autumn and spring values. Diatoms and cryptophytes were predominant as during the non-winter period. However, the relative importance of the Cryptophyta increased by a factor of >2 (11.6 to 25.3%).
11. The phytoplankton composition of Lake Michigan has changed. The following subdominant or dominant species have decreased in abundance from the 60's and 70's: Cyclotella michiganiana, Cyclotella stelligera, Melosira islandica, Synedra acus and Ankistrodesmus falcatus. Oscillatoria limnetica has increased in abundance. Abundance of Rhizosolenia eriensis increased in 1984 after a general decrease since the 60's and 70's.
12. Dominant diatom species included the mesotrophic forms Tabellaria flocculosa and Fragilaria crotonensis and the oligotrophic forms Cyclotella ocellata and Rhizosolenia eriensis. Compared to the 1983 cruises where mesotrophic forms were predominant, the same mesotrophic forms were present in 1984 along with the oligotrophic indicators.
13. The ratio of mesotrophic to eutrophic algal species (trophic ratio) suggests a eutrophic status for nearshore waters in 1977, while the offshore waters in 1970-71, 1983 and 1984 would be in the oligotrophic-mesotrophic range.
14. Based on the classification scheme of Munawar and Munawar (1982), Lake Michigan's algal biomass in 1983 (0.42 mg/m<sup>3</sup>) and 1984 (0.55 mg/m<sup>3</sup>) suggests an oligotrophic status for the offshore waters of Lake Michigan.

15. Phytoplankton abundance of the offshore waters appears to have increased from 1962-63 to 1976-77 but has not significantly changed from 1976 to 1984. Because of the difference in enumeration methodology used in the 1962-63 study compared with the other surveys, the suggested increase in algal abundance from 1962-63 to 1976-77 has to be interpreted cautiously.

16. The trend in zooplankton biomass was similar to the phytoplankton trend between 1976 and 1984 in that no significant change in zooplankton biomass was observed.

17. The Rotifera possessed the largest number of species (29) and relative abundance (67.5%). The Rotifera contributed only 2.6% of the biomass, while the Cladocera accounted for 39.8% of the zooplankton biomass.

18. Abundance of zooplankton generally increased from north to south. The far northern stations (64 and 77) had a significantly higher abundance than the rest of the lake. The northern Stations 64 and 77 and the southern Stations 5 and 6 are best described as nearshore stations.

19. Both the 1983 and 1984 dominant rotifer composition was similar to the nearshore and to Ahlstrom's (1936) offshore composition.

20. The species composition of the predominant rotifers suggests an oligotrophic offshore assemblage. Further support is provided by the high relative abundance of Diaptomus sicilis and Limnocalanus macrurus and the occurrence of Senecella calanoides, all oligotrophic crustacean indicator species.

21. The plankton ratio (Calanoida/Cladocera + Cyclopoida) was high relative to Lake Erie but lower than Lake Huron. Except for the far northern and southern extremes of the lake, the ratio was high and similar indicating a similar high quality of water. At the far northern stations, abundance of the oligotrophic Limnocalanus macrurus and Diaptomus sicilis was lower, while Eubosmina coregoni and Bosmina longirostris, often associated with eutrophic conditions, increased. In addition, four diatom species indicative of mesotrophic conditions were more abundant, and phytoplankton abundance in general was higher at these northern stations suggesting a lower water quality for the northern region. At Station 77, silica and total phosphorus were higher than in the rest of the lake.

22. The changing nature of the zooplankton community of Lake Michigan was evident in 1984. The abundance of Daphnia pulicaria, first observed in 1978, dropped from 376/m<sup>3</sup> in 1983 to 78/m<sup>3</sup> in 1984. Abundance of D. galeata, rare in 1966 and 1968, was three times the density observed in 1954 (1200/m<sup>3</sup>). In general, the larger cladocerans, calanoids and cyclopoid copepods, observed to have decreased in the early 60's, had increased in abundance to values similar to those in August of 1954.

23. With a phytoplankton and zooplankton abundance and biomass between those of Lakes Erie and Huron, the presence of the oligotrophic rotifer association and the oligotrophic crustacean indicator species Diaptomus sicilis and Limnocalanus macrurus, the predominance of mesotrophic and

oligotrophic diatom species, and the similarity of the plankton ratio on the north-south axis suggest that the offshore waters are currently in the upper oligotrophic-lower mesotrophic range (i.e. meso-oligotrophic).

24. A significant change in zooplankton composition has occurred with the establishment of Daphnia pulicaria in the entire offshore region of Lake Michigan. Decline of the alewife population has apparently reduced predatory pressure from alewife releasing the suppressed large-bodied zooplankton such as Daphnia pulicaria (Scavia et al. 1986). In addition, abundances of Leptodora kindtii, Daphnia galeata, Diaptomus ashlandi and Cyclops bicuspidatus have returned to or exceeded abundances observed in 1954 during a period of low alewife abundances.

25. Correlation analysis suggests that the increases in Daphnia galeata mendotae, as well as D. pulicaria, have exerted greater grazing pressures on the phytoplankton community.

## SUMMARY

### Lake Huron

1. In 1984, 315 algal and 53 zooplankton species were observed in Lake Huron. Compared to 1983, a 4.3% and 8.6% reduction in the number of algal and zooplankton species occurred. These fluctuations in species composition are due to both natural and seasonal sampling variability.
2. Compared to Lake Erie, variability in common algal species in Lake Huron between 1983 and 1984 was low. 94% of the common species observed in 1984 were also common species in 1983. 10% of the common algal species observed in 1983 were not common in 1984.
3. Average biomass<sub>3</sub> of the phytoplankton and zooplankton was  $0.38 \pm 0.10 \text{ g/m}^3$  and  $27.3 \pm 2.3 \text{ mg/m}^3$  for the study period. Mean phytoplankton and zooplankton<sub>3</sub> abundance were  $17,200 \pm 890 \text{ cells/mL}$  and  $55,400 \pm 7,200 \text{ organisms/m}^3$ .
4. Diatoms possessed the greatest number of species (156) and biomass (61.9% of the total) in 1984. The Chrysophyta were the second most important division (9.5% of the total) in 1984, which represented a change from 1983 when the Cryptophyta were second in importance.
5. Picoplankton accounted for 83.9% of the total abundance but only 1.4% of the biomass. This finding is similar to that of 1983.
6. Considering biomass, the diatoms were dominant throughout the study period accounting for as much as 72% but never less than 44% of the biomass. The large drop in the relative importance of diatoms in August of 1983 was not observed in 1984. A bloom of Rhizosolenia eriensis in August of 1984, not observed in 1983, was the major cause of the dominance of diatoms during the summer of 1984.
7. Average phytoplankton abundance for the sampling period generally decreased from the northern stations to ~Station 15, where abundance increased and then decreased slightly southward. The mean station zooplankton abundance was higher in the northern half than in the southern half of the lake due primarily to higher rotifer abundance in the north.
8. In general, offshore species composition of phytoplankton has changed little since the early 70's. Stephanodiscus minutus was not common in 1971, 1974, 1975, 1980 and 1983. In 1984 it was common with an average density of 19.4 cells/mL because of the inclusion of winter samples. Abundance averaged 63 cells/mL in February.
9. Vertical distribution studies indicated that an increase in picoplankton, Bacillariophyta and Chrysophyta occurred to a 30-m depth at Station 37. The abundance increase correlates with the decrease in temperature associated with the metalimnion.
10. Both in 1983 and 1984 the dominant diatom assemblages were species characterized as indicators of oligotrophic or mesotrophic conditions.

11. The ratio of mesotrophic to eutrophic algal species (trophic ratio) has not changed since 1971. This suggests that the trophic status of the offshore waters of Lake Huron has not changed since 1971.
12. The Rotifera possessed the largest number of species (31) and relative abundance (56.0%). The Calanoida (42.0%) dominated on a biomass basis followed by the Cladocera (27.5%). Rotifera contributed only 2.5% of the zooplankton biomass.
13. Species composition of zooplankton was similar in 1971, 1974, 1983 and 1984. Diaptomus oregonensis was more prevalent in 1983 and 1984, while D. ashlandi and D. sicilis have increased in abundance since 1971. Limnocalanus macrurus appears to be decreasing in abundance. Bosmina longirostris and Holopedium gibberum were more abundant in 1971 than 1984.
14. Daphnia pulicaria was first observed in offshore waters in 1983. In 1984, lakewide abundance decreased. Within the Cladocera, rank abundance dropped from third in 1983 to fifth in 1984.
15. A new cladoceran species, Bythotrephes cederstroemi, was observed in the offshore waters of Lake Huron.
16. The rotifer community was dominated by an assemblage indicative of oligotrophic conditions in 1983 and 1984. In addition, the calanoid Diaptomus sicilis, an oligotrophic indicator, was fairly abundant.
17. The plankton ratio (Calanoida/Cladocera + Cyclopoid) was high compared to Lake Erie but similar for the entire offshore region, which suggests a similar high quality of water over the entire offshore region except for the far northern Station 61. The plankton ratio at Station 61 was similar to that of the Straits of Mackinac and northern Lake Michigan.
18. The presence of the oligotrophic rotifer assemblage, the domination of the calanoids, the fairly abundant oligotrophic Diaptomus sicilis, and the low zooplankton abundance compared to those of Lakes Erie and Michigan, suggest the offshore waters of Lake Huron in 1983 and 1984 were oligotrophic.
19. Phytoplankton biomass and zooplankton abundance of the offshore waters of Lake Huron in 1971, 1980, 1983 and 1984 were not significantly different. Similarly, offshore zooplankton biomass was not significantly different between 1976 and 1984.
20. The consistency of the trophic ratio and algal biomass through time, the insignificant difference in zooplankton abundance from 1970-1984, the occurrence of oligotrophic and mesotrophic algal indicator species, the oligotrophic zooplankton assemblage, and the similarity of the plankton ratio over the entire offshore suggest that no significant change in the trophic status of the offshore waters of Lake Huron since 1970.
21. With a mean algal biomass of 0.38 and 0.42 g/m<sup>3</sup> for 1984 and 1983, respectively, Lake Huron would be classified as oligotrophic by the classification scheme of Munawar and Munawar (1982).

22. The appearance of Daphnia pulicaria in Lake Huron suggests that the zooplankton community has been released from size-selective planktivory.
23. The correlation of phytoplankton abundance with total phosphorus and zooplankton abundance within individual cruises suggests that "top down" and "bottom up" control of the trophic web of lake ecosystems exists simultaneously and that it varies with season.



## SUMMARY Lake Erie

1. In 1984, 356 species of phytoplankton and 81 species of zooplankton were observed. As compared to 1983, a 4.3% reduction in phytoplankton species, mostly Chlorophyta, and an 18.5% increase in zooplankton species, mostly Rotifera, were observed. As the same sampling enumeration procedure and taxonomy were employed, the observed fluctuations in species composition are due to both natural and sampling variability.
2. Compared to Lakes Michigan and Huron, a high variability in common algal species existed between 1983 and 1984 in Lake Erie. Eighty-four percent of the common species observed in 1984 were also common in 1983. Thirty of the common species observed in 1983 were not common in 1984. The number of common zooplankton species between 1983 and 1984 were similar.
3. Mean phytoplankton and zooplankton abundance were  $45,100 \pm 4,200$  cells/mL and  $159,600 \pm 25,300$  organisms/m<sup>3</sup> for the study period. Average biomass of phytoplankton and zooplankton was  $1.00 \pm .16$  and  $.053 \pm .0062$  g/m<sup>3</sup> in 1984. Phytoplankton biomass varied within Lake Erie. The western basin possessed a greater biomass ( $1.38 \pm 0.23$  g/m<sup>3</sup>) than the eastern ( $0.54 \pm 0.082$  g/m<sup>3</sup>) and central ( $0.76 \pm 0.09$  g/m<sup>3</sup>) basins. Zooplankton abundance increased in a similar fashion into the western basin but not zooplankton biomass.
4. Diatoms possessed the greatest diversity of species (171) and biomass (47.8% of the total) in 1984. Compared to 1970, a significant change in diversity of phytoplankton has occurred. In 1970 only 21 diatom species were observed that accounted for 53% of the biomass. The Chlorophyta possessed the largest number of species (78) in 1970.
5. Picoplankton accounted for 89.6% of the total abundance. A similar finding was observed in 1983.
6. Diatoms were dominant in April and May and were succeeded by the Cryptophyta in July and the Chlorophyta in August. By December and through the winter months, the diatoms were again dominant.
7. The historically highly productive western basin has had a steady decrease in algal biomass from 1958 to 1984. Similarly, chlorophyll *a* levels have decreased in all basins, but most dramatically in the western basin. However, algal biomass is still higher in the western basin than in the central and eastern basins.
8. Lakewide, the mean weighted algal biomass was 3.4, 1.5 and 0.8 g/m<sup>3</sup> in 1970, 1983 and 1984, respectively. A 56 to 76% reduction in algal biomass has occurred in offshore waters of the lake from 1970 to 1983/84.
9. Although occurrences of common and dominant species were similar in 1970, 1983 and 1984, dramatic decreases in the biomass of these species were evident. For example, a 96% reduction in the maximum biomass of the nuisance species Aphanizomenon flos-aquae has occurred since 1970. The

eutrophic indicator species Stephanodiscus binderanus and Fragilaria capucina have had a >90.% reduction in maximum biomass.

10. Asterionella formosa has not been prevalent in Lake Erie since prior to 1950. In the 1984 spring cruises, A. formosa was the dominant species on a biomass basis. Melosira islandica, a mesotrophic indicator not common in 1983, was common in 1984.

9. The Rotifera possessed the largest number of species (48) and relative abundance (80.1%) of the zooplankton. On a biomass basis, the Rotifera represented only 13.6% of the zooplankton biomass while the Cladocera contributed 40.5% of the biomass.

10. A shift in zooplankton composition is occurring with a new species Daphnia pulicaria being observed for the first time in 1984. On a biomass basis, D. pulicaria was the dominant Cladocera in the lake with a major bloom in August. However, it was most prominent in the central and eastern basins. The prevalence of the eutrophic cyclopoid Cyclops vernalis has decreased within the lake, especially within the central and eastern basins.

11. A decrease in summer Cladocera and Copepoda abundance in the western basin is suggested from 1961 to 1984. Rotifera abundance in the western basin has increased since 1934. A number of eutrophic rotifer indicator species had abundances restricted to or significantly higher in the western basin. The plankton ratio also suggests a more productive status for the western basin.

13. There is a lack of dominance of eutrophic rotifer indicator species for the entire lake. This suggests that Lake Erie in 1984 as a unit is not eutrophic. The number of dominant eutrophic algal species has decreased, while the number of dominant mesotrophic species has increased; that is, the trophic ratio has increased, suggesting an improvement in water quality.

14. Evidence of a shift in trophic status of Lake Erie since 1970 is provided by the trophic ratio, the plankton ratio, phytoplankton and zooplankton indicator species, declines in total abundance and biomass of total phytoplankton and zooplankton since the mid-60's and 70's, declines in abundance of nuisance species and eutrophic species, declines in total phosphorus and chlorophyll a, and the current total biomass and abundance of plankton.

15. The trophic condition of Lake Erie appears to be improving. However, compared to Lakes Huron and Michigan in 1983 and 1984, biomass of phytoplankton and zooplankton was higher, the plankton and trophic ratios were lower, and the phytoplankton and zooplankton species compositions suggest a more productive status for Lake Erie.

16. Based on the classification schemes of Vollenweider (1968) and Munawar and Munawar (1982) utilizing maximum and average algal biomass, the western basin would be meso-eutrophic, the central basin mesotrophic, and the eastern oligo-mesotrophic. This conclusion is supported by other indicators of the trophic status noted above.

17. The decreases in phytoplankton abundance, chlorophyll, total phosphorus and turbidity are consistent with expectations of long-term nutrient control. However, the significant changes in the composition of the zooplankton community with the appearance and establishment of the large cladoceran Daphnia pulicaria are attributed to a change in planktivory. The planktivorous emerald and spottail shiners have dramatically declined, perhaps due to a resurgence of the walleye and the salmonine stocking programs.

## INTRODUCTION

Nutrient loading of lakes and rivers, navigation, fish management policies, fishing, shoreline alteration, contaminant production and, in general, economic development, ultimately affect the lake ecosystem. Effects of perturbations are not always known and can not always be monitored individually in large, complex systems such as the Great Lakes. Biological monitoring is an integrative monitoring strategy (Johannson et al. 1985). Ecosystems respond to stress with compensatory changes in community structure and function mediated at the population level (Boesch and Rosenberg 1981). Therefore, changes in ecosystem health can be detected by monitoring changes in the biotic community (Nicholls et al. 1980, Dillon et al. 1978).

Any monitoring program must first document the state of the ecosystem, namely, the species composition, biomass and production of each community component, including the normal range of temporal and spatial variation. The second step is to examine the relationship and interactions amongst the ecosystem components in order to interpret and possibly predict future changes in community structure or function. Thus, the value of such monitoring programs goes far beyond its surveillance capabilities; it can form the backbone for research activities, thereby encouraging a detailed understanding of the system.

This project reported here was initiated by the United States Environmental Protection Agency, Great Lakes National Program Office (GLNPO), to analyze phytoplankton and zooplankton samples from Lakes Erie, Huron and Michigan taken in 1984 and the winter of 1985. Because phytoplankton are sensitive to water quality conditions and possess short

carbon turnover rates, the determination of phytoplankton abundance and species composition has become established as a method to trace long-term changes in the lakes (Stoermer 1978, Munawar and Munawar 1982). Similarly, zooplankton have value as indicators of water quality and the structure of the biotic community and have proved useful for complementing phytoplankton to assess the apparent effects of water quality conditions (Gannon and Stemberger 1978) and of fish populations (e.g. Brooks and Dodson 1965) on biota. This report represents the second year of similar sampling intensity and pattern of the offshore region of Lakes Erie, Huron and Michigan.

An in-depth planktonic (phyto- and zooplankton) comparison is presented based on extensive seasonal lake-wide surveys including the winter of 1985. This comparison was achieved by the application of standard and consistent identification, enumeration and data-processing techniques of plankton that were collected along north-south transects in Lakes Huron and Michigan and east-west transects in Lake Erie. In addition, the vertical distribution of phytoplankton was examined in each lake during the year.

The primary objectives of this report include:

- (1) To organize plankton data for use in eutrophication models;
- (2) To characterize the composition and abundance of the phytoplankton and zooplankton for comparison with past conditions to the extent that they are known;
- (3) To provide firm documentation with which future assessment of the changes in water quality of the lakes can be made;
- (4) To characterize the water quality by studying the abundance and autecology of phytoplankton and zooplankton; and

- (5) To characterize within and between year plankton variance to allow better long-term assessments of changes in plankton structure.

## METHODS

### Sampling Sites

Phytoplankton and zooplankton samples from Lakes Erie, Huron and Michigan were collected by GLNPO personnel during several cruises (9-11) during the spring, summer and autumn of 1984 and the winter of 1985. Collection dates and station locations of routine plankton sampling are given in Tables 1 and 2 and in Figures 1 - 3. Locations of sampling sites on Lakes Michigan and Huron were not seasonally consistent (Tables 3 and 4). By design, alternate east-west stations were sampled (e.g. 5 or 6, 10 or 11; Fig. 1) on various cruises. This selection of sites was based on previous studies which indicated that adjacent east-west sites were within homogeneous areas of Lake Michigan (Moll et al. 1985). For analytical purposes, east-west stations are combined, assuming that no significant difference in species abundance and composition exist between east-west stations, to give a single north-south transect. All sites are also part of the Great Lakes International Surveillance Program.

### Chemistry

Only selected water quality variables collected during the study are presented in this report. Results of the complete water chemistry investigation are reported elsewhere (Lesht and Rockwell 1987). Methods used were standard procedures (Lesht and Rockwell 1987).

### Phytoplankton

An 8-liter PVC Niskin bottle mounted on a General Oceanics Rosette sampler with a Guildline electrobathythermograph (EBT) was used to collect phytoplankton. One-liter composite phytoplankton samples were obtained at each station by compositing equal aliquots from water samples collected at

depths of the surface, 5m, 10m and 20m as allowed by total water depth. Vertical distribution samples were collected at selected stations from the surface, 5m, 10m, 15m and 20m (occasionally to 30m).

Phytoplankton samples were immediately preserved with 10 mL of Lugol's solution, while formaldehyde was added upon arrival in the laboratory. The settling chamber procedure (Utermohl 1958) was used to identify (except for diatoms) and enumerate phytoplankton under phase contrast microscopy at a magnification of 500x. Objects (spheres < 1 $\mu$ m, rods < 3 $\mu$ m length) possessing a bluish cast were identified as picoplankton, while those appearing as dull grey were not counted. The designation Haptophyte spp. used represents a collection of morphological forms more appropriately titled Haptophyceae. A second identification and enumeration of diatoms at 1250x was performed after the organic portion was oxidized with 30% H<sub>2</sub>O<sub>2</sub> and HNO<sub>3</sub>. The cleaned diatom concentrate was air dried on a cover slip and mounted on a slide (75x25mm) with HYRAX<sup>TM</sup> mounting medium. Identifications and counts were done by Dr. Norman A. Andresen, Mr. Mark A. Lamb, Dr. Louis L. Lipsey, Ms. Heather K. Trull and Dr. Marc Tuchman of the Bionetics Corporation.

The cell volume of each species was computed by applying average dimensions from each sampling station and date to the geometrical shape such as sphere, cylinder, prolate spheroid, etc., that most closely resembled the species form. At least 10 specimens of each species were measured for the cell volume calculation. When fewer than 10 specimens were present, those present were measured as they occurred. For most organisms, the measurements were taken from the outside wall to outside wall. The protoplast was measured with loricated forms, while the individual cells of filaments and colonial forms were measured. For



comparative purposes, biovolume ( $\mu\text{m}^3/\text{L}$ ) was converted to biomass ( $\text{mg}/\text{m}^3$ ) assuming the specific gravity of phytoplankton to be 1.0 ( $\text{mm}^3/\text{L}=\text{mg}/\text{m}^3$ ) (Willen 1959, Nauwerck 1963).

### Zooplankton

A Willco Model 30-E28 conical style net (62- $\mu\text{m}$  mesh net; D:L ratio = 1:3) with 0.5m opening (radius=0.25m) was used to collect, where possible, two vertical zooplankton samples at each station. Vertical tows were taken from 2m above the bottom to the surface (long tow) and from 20m to the surface (short tow). The short tow was analagous to an epilimnetic tow in stratified waters. Filtration volume and towing efficiency were determined with a Kahl flow meter (Model 00SWA200) mounted in the center of the net. Filtration efficiency averaged 83.4, 75.9 and 85.8%, respectively, for Lakes Erie, Huron and Michigan for the entire sampling season. Following collection, the net contents were quantitatively transferred to 0.5-liter sample bottles, narcotized with club soda and preserved with 5% formalin. Identification and enumeration of zooplankton followed Gannon (1971) and Stemberger (1979) and were performed by D. Page, H. Trull and L. Stokes of the Bionetics Corporation.

Raw counts were converted to number/ $\text{m}^3$  by Bionetics, Inc. The volume of each rotifer species was computed by using the geometrical shape that most closely resembled the species (Downing and Rigler 1984). It is essential that the measurements are made on the population being studied since they vary in different habitats for some species up to 100% and more (Bottrell et al. 1976). For each cruise, length of at least 20 specimens of each rotifer species was measured. Width and depth were also measured on one date for each lake to develop length-width and length-depth ratios for use in the simplified formulas of Bottrell et al. (1976). Assuming a

specific gravity of one, volume was converted to fresh weight and to dry weight assuming a ratio of dry to wet weight of 0.1 (Doohan 1973) for all rotifer species except Asplanchna spp. A dry weight/wet weight ratio of 0.039 was used for Asplanchna spp. (Dumont et al. 1975).

Because of the considerable variability in length and thus weight encountered in the Crustacea, the dry weights of Crustacea were calculated using length-weight relationships (Downing and Rigler 1984). Average length of crustaceans (maximum of 20 for each station) was determined for each station of each cruise. A comparison of calculated weights to measured weights of Crustacea in Lake Michigan suggests good agreement at the minimum weight range (Table 5). The use of the mean and the high end of the range for comparison is tenuous because they are affected by sample size and selective feeding of predators. The weight of the Copepoda nauplii followed Hawkins and Evans (1979).

### Data Organization

Abundances and dimensions of each species of phytoplankton and zooplankton were entered into a Prime 750 computer using the INFO (Henco Software, Inc., 100 Fifth Avenue, Waltham, Mass.) data management system. Biomass was calculated for phytoplankton and zooplankton and placed into summaries for each sampling station containing density (cells/mL), biovolume ( $\mu\text{m}^3/\text{mL}$ ) and relative abundances of species. In addition, each division was summarized by station. Summary information is stored on magnetic tape and is available for further analysis.

### Definitions

Common phytoplankton species were defined as having an abundance of  $>0.1\%$  of the total cells or  $>0.5\%$  of the total biovolume.

Common crustacean zooplankton species were defined as having  $>0.1\%$  of the total abundance or  $>1.0\%$  of the total biomass. Rotifer species were considered common if they accounted for  $>1.0\%$  of the total abundance.

Species diversity refers simply to the number of species observed.

Dominance refers to a community property reflected in the relative abundance pattern of species. A species was considered to be dominant if it possessed the highest relative abundance or biomass of a taxonomic grouping (i.e. division).

Importance refers to a group of measurements by which the species in a community can be compared (Whittaker 1975). Abundance or biomass was the importance value used in the discussion.

## RESULTS AND DISCUSSION

### LAKE MICHIGAN

#### Phytoplankton

Species lists (Table A1) and summary tables of abundance (Table A2) and biovolume (Table A3) are in Volume 2 - Data Report. A summary of water chemistry parameters is presented in Table 6.

#### Annual Abundance of Major Algal Groups

The phytoplankton assemblage of 1984 was comprised of 327 species representing 91 genera from eight divisions. Compared to 1983, a ~15% reduction in the number of genera and species was observed. This difference was mostly attributable to a decrease in the number of Chlorophyta, Chrysophyta and Cyanophyta (Table 7).

Similar to 1983, the Bacillariophyta possessed the largest number of species (166) and biovolume (70.0% of the total, Table 8), while the second largest number of species (63) was observed for the Chlorophyta (Table 7). The Cryptophyta, as in 1983, accounted for the second highest biovolume (11.6%) (Table 8). Highest overall densities were attained by the picoplankton (82.9% of the total). Both the Pyrrophyta and the Chlorophyta had much lower biovolumes in 1984 than in 1983 (Table 8). The annual average phytoplankton density and biomass were  $22,220 \pm 1,400$  cells/mL (mean  $\pm$  S.E.) (29,839 cells/mL, 1983) and  $0.55 \text{ g/m}^3 \pm 0.038$  (mean  $\pm$  S.E.) ( $0.42 \text{ g/m}^3$ , 1983), respectively.

#### Seasonal Abundance and Distribution of Major Algal Groups

Seasonally, abundance (cells/mL) was low during the spring and had increased by July. Because sampling in the present study was designed to monitor the early pre-bloom conditions, the spring bloom observed in May,

June and July of 1976 (Bartone and Schelske 1982) was not observed in 1984. A secondary abundance maxima was observed in August (Fig. 4a) but was not observed in the biovolume seasonal distribution (Fig. 4b). During August, a general downward trend in biomass occurred. Because samples were not taken in October, the large autumn peak (48,305 cells/mL) seen in 1983 (Makarewicz 1987) was not observed in 1984. Similarly, a fall bloom was not observed in 1976 by Bartone and Schelske (1982). This was attributed either to a weak bloom that was not observed or to the occurrence of the bloom at a time when samples were not taken.

Considering biovolume, the Bacillariophyta were dominant throughout the study period accounting for as much as 80%, but never less than 55%, of the phytoplankton biovolume (Fig. 5). The overwhelming dominance of the diatoms throughout the study period precluded the prominent seasonal succession of algal divisions observed in 1983 (Makarewicz 1987).

The large drop in biovolume of Bacillariophyta (to ~10%) noted in August of 1983 (Makarewicz 1987) was not observed in 1984. A bloom of Rhizosolenia eriensis during the summer of 1984, not observed in 1983, was the major cause of the dominance of the diatoms in August (Table 9). For example, on the 12-14 August cruise, abundance of R. eriensis was only 17.5 cells/mL, but the biovolume per cell was high. Thus, this one species accounted for 26.9% of the total biovolume during the cruise.

The small decrease in diatoms in August of 1984 corresponded with an increase in the Cryptophyta, while in 1983 the major decline in diatoms corresponded with an increase in the Pyrrophyta. A similar shift in biovolume composition was observed in 1976 with diatoms decreasing to 17% in August when greens and blue-green algae predominated (Bartone and Schelske 1982).

### Regional and Seasonal Trends in the Abundance of Common Taxa

Common species (Table 10) were arbitrarily defined as those possessing a relative abundance of  $>0.1\%$  of the total cells or  $>0.5\%$  of the total biovolume. Forty-three common species were observed in 1984-85 compared to 45 in 1983. Seventy-six percent of the common species observed in 1984 were also common species in 1983; thirty-one percent of the common species observed in 1983 were not common in 1984 (Table 11) (Makarewicz 1987). The cause of these differences is difficult to evaluate. Natural annual variability in the lake has never been evaluated and cannot be evaluated until a longer data set exists. Seasonal sampling variability exists between 1983 and 1984 and is the most probable cause for the species differences observed. For example, Dictyosphaerium ehrenbergianum was a common species for the 1984-85 survey, but not the 1983 survey, by virtue of the inclusion of a winter sampling period in 1984-85. D. ehrenbergianum was prevalent only in the winter of 1985. Since no winter samples were analyzed in 1983-1984, this species was not a common species for the entire 1983 sampling period.

Because of the similarity between the 1984 common species list and the 1983 list, a species by species description of autecology and regional and seasonal trends are not warranted here and can be referred to in Makarewicz (1987). Only new common species are discussed below.

#### Bacillariophyta

##### Cyclotella ocellata Pant.

Cyclotella ocellata was observed in the southern basin of Lake Michigan in low numbers in 1963 (Stoermer and Kopczynska 1967a). In 1967 this species was most abundant at offshore localities in the northern part of the lake although occasional populations were noted in the southern

basin (Stoermer and Yang 1970). In 1972 Holland (1980) reported this species as most abundant during the summer (maximum abundance range = 50-70 cells/mL). However, it was not a common species in 1983 (Makarewicz 1987). Cyclotella ocellata is generally abundant in areas of the Great Lakes which have not undergone significant eutrophication (Stoermer and Kreis 1980); i.e., associated with oligotrophic conditions in the Great Lakes (Stoermer and Yang 1970).

In 1984 abundance increased into the summer (mean maximum station abundance = 39 cells/mL), dropped by mid August and stayed low in late autumn (Fig. 6a). Mean abundance and biomass were 23.3 cells/mL (0.10% of the total cells) and  $2.1 \text{ mg/m}^3$  (0.38% of the total biomass) (Table 10). A maximum abundance of 265 cells/mL occurred on 8-9 July at Station 17. Mean abundance was high at the most northerly station (77) (45.2 cells/mL) and at Stations 17 and 22 (46.5 cells/mL) (Fig. 6a, Fig. 9a).

Synedra ulna var. chaseana Thomas

Stoermer and Kopczynska (1967a and b) reported this variety, along with S. ulna var. danica, as reaching 100 cells/mL in early August of 1962. Although several members of the genus occur in Lake Michigan, the only numerically important taxa were S. ulna var. chaseana and S. ulna var. danica in 1962 and 1963. Abundance of this variety was low in 1983 (0.16 cells/mL) (Makarewicz 1987). Stoermer and Yang (1970) characterized S. ulna var. chaseana as an oligotrophic offshore dominant.

In the present study, a July maximum was observed followed by a population crash by early August (Fig. 6b). Spring, autumn and winter abundances were low. Mean density and biomass were 2.2 cells/mL and  $17.2 \text{ mg/m}^3$ , respectively. This species represented 3.1% of the total biomass

for the entire sampling period. Maximum abundance was 23 cells/mL at Station 34 in early July.

Synedra filiformis Grun.

Earlier work had suggested this species to be largely restricted to the offshore waters (Stoermer and Yang 1970) and highly oligotrophic regions such as Grand Traverse Bay (Stoermer et al. 1972). However, it was fairly abundant in Green Bay in 1977 with an average density of 14.3 cells/mL. Similarly, density averaged 36.9 cells/mL (0.95% of the population) in the nearshore of southern Lake Michigan in 1977. Average abundance in 1983 was 2.59 cells/mL (maximum of 25.5 cells/mL).

Abundance was high in April, May and July of 1984 (Fig. 6c). Mean seasonal abundance reached a maximum of 30.8 cells/mL in July. The maximum density observed was 118 cells/mL at Station 34 on 7-9 July. Average abundance and biomass for the non-winter period was 11.2 cells/mL and  $4.2 \text{ mg/m}^3$ , respectively (Table 10).

Rhizosolenia longisetia Zach.

During 1962 and 1963, R. eriensis was the dominant member of this genus with a small population of R. gracilis also noted in Lake Michigan (Stoermer and Kopczynska 1967a). Holland (1980) observed densities of R. eriensis reaching ~750 cells/mL in 1970 but did not report any other species of Rhizosolenia. In the 1977 study of Green Bay (Stoermer and Stevenson 1979), only R. eriensis (maximum = 90 cells/mL) and R. gracilis (maximum = 46.1 cells/mL) were observed. Similar maximum abundances were observed for the nearshore zone of southern Lake Michigan [R. eriensis (maximum = 81.7 cells/mL); R. gracilis (maximum = 46.1 cells/mL)] (Stoermer and Tuchman 1979). In 1983, R. eriensis and R. longisetia (R.



longiseta = R. gracilis) were observed (Makarewicz 1987). In the present study, R. longiseta was the more abundant, but R. eriensis contributed a greater biomass (Table 10).

R. longiseta abundance was highest in the spring, appeared to decrease to late July and increased in mid-August. Late autumn and winter abundances were low (Fig. 6d). Average abundance was 21.2 cells/mL representing 0.1% of the total cells and 4.38% of the total biomass (Table 10).

#### Nitzschia lauenburgiana Hust.

Stoermer and Kopczynska (1967a), Holland (1980) and Stoermer and Tuchman (1979) did not report this species in Lake Michigan. Stoermer and Yang (1970) did not list N. lauenburgiana as a dominant plankton in the Great Lakes. However, it has been reported as occurring in Green Bay (mean = 0.41 cells/mL; maximum = 16.1 cells/mL) (Stoermer and Stevenson 1979). In 1983 this species occurred only seven times (mean = 1.36 cells/mL). In 1984 it was a common species by virtue of its large biovolume (Table 10). Maximum mean seasonal abundance occurred during the spring sampling (Fig. 7a).

#### Chlorophyta

##### Oocystis submarina Lagerh.

Stoermer and Kopczynska (1967a) noted that in 1962 and 1963 the three most common species of Oocystis were O. elliptica, O. submarina and O. lacustris. Abundance ranged from 2 to 10 cells/mL. Oocystis spp. was one of the most abundant taxa observed in August and October of 1977 in Green Bay (Stoermer and Stevenson 1979). Mean density was 133.8 cells/mL representing 2.4% of the population. Similarly, the abundance of Oocystis

spp. was relatively high (mean = 30.9 cells/mL; 0.57% of the population) in the nearshore of Lake Michigan in 1977 (Stoermer and Tuchman 1979).

Q. submarina was observed in 1983 but was not a common species (mean = 0.2 cells/mL; <.01% of total population). In the present study, a maximum pulse of 254 cells/mL was observed, but the average was considerably lower (mean = 26.5 cells/mL; 0.12% of the total population) (Table 10). Abundance was low during the spring and progressively increased to a peak in late August. Abundance was again low by late autumn (Fig. 7b). Generally, abundance of Q. submarina was higher at the northern stations (Stations 64 and 77) and the southern stations (Stations 6, 10, 18 and 22) as compared to the mid-lake region (Fig. 9b).

#### Dictyosphaerium ehrenbergianum Naeg.

In the 1962-63 study of the southern basin of Lake Michigan, Dictyosphaerium was observed in the autumn (usually <1 cell/mL, occasionally 5 cells/mL) but was not noted in the spring (Stoermer and Kopczynska 1967a and b). Stoermer and Ladewski (1976) reported the abundance of this species as being high in 1971 (peaks over 200 cells/mL, many occurrences over 100 cells/mL). Average abundance in Green Bay in 1977 was 10.3 cells/mL with a maximum of 106.8 cells/mL (Stoermer and Stevenson 1979).

This was not a common species in 1983 (Makarewicz 1987) and would not have been in 1984 without the addition of the winter sampling date. In 1984, mean abundance was 23.6 cells/mL (0.11% of the total population) (Table 10) with a maximum abundance of 298 cells/mL at Station 6 on 7 February 1985. Mean cruise abundance for the February cruise was 105.2 cells/mL. Seasonally, spring abundance was ~25 cells/mL followed by a decrease into the summer and a major buildup into late autumn and winter

(Fig. 7c). Abundance was substantially greater in the southern half of the lake (Fig. 9c).

## Cryptophyta

### Cryptomonas rostratiformis Skuja

Little historical information is available on the distribution or occurrence of this species in Lake Michigan. Much of the previous work simply identifies a few major species of Cryptomonas and then lumps the other occurrences under Cryptomonas sp. For Green Bay, C. marssonii, C. ovata, C. erosa and C. gracile were observed in 1977 but apparently not C. rostratiformis.

In 1983 C. rostratiformis was not a common species (Makarewicz 1987). Abundance was low (1.3 cells/mL, Table 10) in 1984 but biovolume was high (4.57 mg/m<sup>3</sup>, 0.84% of total biovolume). Seasonally, abundance was low in the spring and early summer, increased to ~2 cells/mL in August, and maintained that level of ~2 cells/mL into February (Fig. 7d).

## Cyanophyta

### Oscillatoria minima Gickl. H.

Both Ahlstrom (1936) and Stoermer and Kopczynska (1967a) list O. mougeotii as the only species of the genus abundant in their collections. O. limnetica and O. bornetii were also observed by Stoermer and Ladewski (1976). O. agardhii, O. limnetica, O. subbrevis, O. tenuis and O. minima were observed in 1983 (Makarewicz 1987) and 1984. In 1983, O. limnetica and O. agardhii were common, while in 1984 O. limnetica and O. minima were common.

O. minima abundance was high in 1984 (mean abundance = 175.5 cells/mL, 0.79% of the total population) (Table 10). Maximum abundance

was 4,132 cells/mL at Station 32 on 12 August 1984. Abundance was greatest during the summer period (Fig. 8). Geographically, abundance appears greatest at the mid-lake stations (Fig. 9d).

### Vertical Distribution

Besides the routine integrated samples, a vertical series of samples were taken at two stations (18 and 47) on 15 August 1984 and were not integrated. Abundance increased with depth at Station 47 and can be primarily attributed to an increase in the picoplankton (Fig. 10a). However, Bacillariophyta, Chrysophyta, Cryptophyta, Chlorophyta and Cyanophyta also increased with depth (Fig. 10b). With depth, species diversity increased. In particular, a 100%+ increase in diatom species was observed between the surface and the 10-m depth (Table 12). Species such as Asterionella formosa, Fragilaria crotonensis, Cyclotella ocellata (Fig. 10c), Rhizosolenia eriensis, R. longisetia, Chroomonas norstedtii, Rhodomonas minuta var. nannoplanktica, Oscillatoria limnetica and O. minima all increased in abundance with depth. One species, Cyclotella comensis (Fig. 10c), was observed to decrease with depth.

A similar increase in non-picoplankton species was not observed at Station 18 (Fig. 11a). In contrast to Station 47, the abundance of the Bacillariophyta and Cryptophyta did not vary in the top 20m of the water column. The Chrysophyta decreased with depth. All other divisions, except the Cryptophyta, increased in abundance to the 30-m depth (Fig. 11b). As with Station 47, species diversity of Bacillariophyta increased with depth, not to the 20-m depth as in Station 47, but from the 20 to 30-m depth.

The increase in the abundance and species of diatoms correlates well with the decrease in temperature associated with the metalimnion (Fig.

11b). The appearance of an apparent sub-surface maximum in phytoplankton abundance is of interest but not surprising. Brooks and Torke (1977), Mortonson (1977) and Bartone and Schelske (1982) have previously reported a sub-surface chlorophyll maximum in Lake Michigan. Reasons for the existence of the layer are not clear and are apparently complex, encompassing physical, chemical and biological factors (Bartone and Schelske 1982).

### Winter Cruise

Biomass and abundance were low during the winter and not significantly different from the autumn and spring values (Fig. 4). As in the non-winter season, the Bacillariophyta (42.8% of the biomass) and the Cryptophyta (25.3% of the biomass) were the dominant divisions. However, the Cryptophyta accounted for twice the biomass than during the non-winter season (11.6%).

Stephanodiscus minutus was the dominant winter diatom (mean = 24.2 cells/mL); however, this species was not a common species during the rest of the year. Other major winter diatoms, Fragilaria crotonensis, Tabellaria flocculosa and Asterionella formosa were common species (Table 10) during the non-winter period.

Dicthyosphaerium ehrenbergianum was the dominant Chlorophyta. Seasonally, abundance of this species was low throughout the year and reached its peak abundance in winter (93.5 cells/mL). By virtue of its high winter abundance, it became a common species for the year (Table 10).

Common winter species of Cryptophyta and Cyanophyta were Rhodomonas minuta var. nannoplanktica and Oscillatoria limnetica and minima, which were also common non-winter species.

## Historical Changes in Species Composition

### Division Trends

Because common species abundance, biomass and distribution are similar between 1983 and 1984, division and species trends are essentially the same as those in an earlier report (Makarewicz 1987) and do not need to be repeated in detail here. In August of 1962, an analysis of samples from southern Lake Michigan revealed that the diatoms were numerically dominant (Stoermer and Kopczynka 1967a). Relative abundance of diatoms was never lower than ~70% of the total assemblage at all stations. By 1969 green, blue-green and golden brown algae were the major phytoplankton components (Schelske and Stoermer 1972). Similarly, Schelske et al. (1971) observed that blue-green and green algae constituted 56 to 85% of the phytoplankton during August and September. In a detailed study of southern Lake Michigan, Stoermer (cited in Tarapchak and Stoermer 1976) observed that blue-green algae contributed up to 80% of the phytoplankton cells in August of 1971.

By 1977, another shift in algae composition was evident. Relative abundance of blue-greens dropped to 22.9% in August. However, flagellates (~42%) rather than diatoms (22%) were the dominant group of algae (Rockwell et al. 1980). A similar composition as in 1977 was observed in August of 1984 (diatoms = 12.2%, blue-greens = 16.4%, unidentified flagellates = 42.1%) if picoplankton are not included in the analysis. However, in addition to the cyanophytes, both the cryptophytes and chrysophytes were still numerically more important than the diatoms (Table 8) in 1983, while in 1984 the chrysophytes were. The numerical decline of the diatoms has been attributed to the high phosphorus loading and

concomitant silica depletion (Schelske and Stoermer 1971). On a biomass basis, however, diatoms were the dominant group in 1983 and 1984.

### Species Trends

Changes in common species between 1983 and 1984 are discussed under Regional and Seasonal Trends in the Abundance of Common Taxa (Page 20). Dominant diatoms in 1983 included the numerically dominant Cyclotella comensis, Fragilaria crotonensis and Melosira italica subsp. subarctica; on a biomass basis, Tabellaria flocculosa was predominant (Makarewicz 1987). In 1984 Cyclotella comensis and Fragilaria crotonensis, along with Cyclotella ocellata, were numerically dominant. M. italica subsp. subarctica was common but not dominant. On a biomass basis, Rhizosolenia erlensis and Tabellaria flocculosa were predominant in 1984.

The Haptophyceae, Monoraphidium contortum (Chlorophyta), Dinobryon sociale var. americanum (Chrysophyta), Rhodomonas minuta var. nannoplanktica and Chroomonas norstedii (Cryptophyta), Anacystis montana var. minor and Oscillatoria limnetica (Cyanophyta) were numerically dominant in both 1983 and 1984.

Of the 1983 and 1984 dominant diatoms, only Fragilaria crotonensis and perhaps Tabellaria flocculosa were the major components of the diatom assemblage in 1962-63. Stoermer and Kopczynska (1967a) noted taxonomic difficulties with Tabellaria and noted that most populations of Tabellaria "are probably to be referred to I. fenestrata ...."

The dominant species of Cyclotella in 1962-63 was C. michiganiana. Rockwell et al. (1980) reported that Cyclotella spp. were common in 1977 but were never dominant. A dramatic decrease in some species of Cyclotella, such as C. michiganiana and C. stelligera, which were offshore dominants in August of 1970, was evident (Table 13). Cyclotella comensis,

believed to be tolerant of higher nutrient and lower silica concentrations than most members of this genus, was the numerically dominant diatom in the offshore waters. In 1984, however, Cyclotella ocellata, a species generally associated with oligotrophic conditions, was also dominant.

Yearly variation in dominance of species of Melosira was evident. Melosira islandica was dominant in 1962-63. In 1983 M. islandica was present (mean = 12.1 cells/mL), but M. italica subsp. subarctica (mean = 37.6 cells/mL) was more abundant. In 1984 M. islandica and M. italica subsp. subarctica had similar abundances (~10-12 cells/mL) (Table 10). Similarly, Synedra acus was common throughout the southern basin in 1977 (Rockwell et al. 1980) but in 1983 represented only 0.1% of the total cells.

Makarewicz (1987) has suggested an apparent decline in R. eriensis since 1962. In May of 1962, relatively high (100 cells/mL) populations were observed in southern Lake Michigan (Stoermer and Kopczynska 1967a). During May and June of 1970, mean abundances for offshore stations were 63 and 611 cells/mL, respectively (Holland and Beeton 1972). Rockwell et al. (1980) reported a mean density of 28.7 cells/mL for R. eriensis during June of 1977. Abundance in 1983 was 2.6 cells/mL for the entire lake. A bloom (133 cells/mL) in the northern Station 77 did occur in October. In 1984-85, mean lake abundance increased to 18.2 cells/mL. Similar to species of Melosira, considerable yearly variation in abundance of Rhizosolenia from 1983 to 1984 was observed.

Ankistrodesmus falcatus increased in abundance to 1977 and had decreased by 1983. Ahlstrom (1936) reported this species as rare, but Stoermer and Kopczynska (1967a) noted that it had increased by 1962-63 (range = 20-60 cells/mL). Rockwell et al. (1980) suggested that by 1977



It had increased further (range = 20-160 cells/mL). In 1983 this species was observed only once during the study at Station 32 (6.5 cells/mL). This species was not observed in 1984.

Dominant chrysophytes in 1962-63 were Dinobryon divergens, D. cylindricum and D. sociale (Stoermer and Kopczynska 1967a). Rockwell et al. (1980) reported them as dominant or subdominant offshore. With the exception of D. cylindricum in 1984, D. divergens, D. cylindricum and D. sociale were common species in 1983 and 1984. However, the haptophytes were numerically the dominant group within the chrysophytes in 1983 and 1984.

Dominant cryptophytes in 1983 and 1984 included Cryptomonas erosa var. reflexa, C. erosa and Rhodomonas minuta var. nannoplanktica. Stoermer and Kopczynska (1967b) and Stoermer (1978) reported these species as uncommon in Lake Michigan, but Vollenweider et al. (1974) noted these species as commonly found. Similarly, Munawar and Munawar (1975), Claflin (1975) and Rockwell et al. (1980) had reported C. erosa and R. minuta var. nannoplanktica to be dominant, abundant and perhaps increasing in number. From the 1983 and 1984 study, it is apparent that C. erosa was numerically uncommon but on a biomass basis was the second most important cryptophyte (Table 10). Evaluation of abundance of R. minuta in earlier studies was not possible because it was grouped into phytoflagellates, flagellates or simply Rhodomonas. What can be reported about Rhodomonas minuta var. nannoplanktica is that in 1983 and 1984 it was the dominant cryptophyte on a numerical basis.

Oscillatoria limnetica has become more prevalent in the lake. Ahlstrom (1936) and Stoermer and Kopczynska (1967a) listed O. mougeotii as the only species of this genus abundant in their collections. Stoermer

and Ladewski (1976) reported that Q. limnetica had generally increased in abundance in Lake Michigan. Rockwell et al. (1980) observed that Q. limnetica was common throughout the basin in April and June and was especially abundant in September of 1977 at certain stations. Not considering the picoplankton, which were not counted in previous studies, Q. limnetica was the numerically dominant offshore blue-green algae in 1983 (Makarewicz 1987) and was second in abundance in 1984 (Table 10). Anacystis montana var. minor was the dominant blue-green algae in 1984 (Table 10).

### Picoplankton

Picoplankton abundance in 1984 (mean = 18,409; maximum of  $4.3 \times 10^4$  cells/mL) was not dissimilar from 1983 (mean = 23,607; maximum of  $1 \times 10^5$  cells/mL). On a numerical basis, the picoplankton represented 82.8% of the total cells in 1984. Their dominance of the phytoplankton community in 1984 was comparable to that in 1983 (89.4% of total cells). Prior to the 1983 study (Makarewicz 1987), no other researchers on Lake Michigan have routinely reported this group of organisms. Because of the overwhelming dominance of this group, analysis and discussion of this group would be facilitated with verification of the systematics of the spheres (Anacystis marina?), rods (Coccochloris penicystis?) and the spherical-flagellates.

### Geographical Abundance and Distribution

Average phytoplankton abundance for the non-winter sampling period generally decreased from the north (Station 77) to the south at Station 57 (Fig. 12). Overall abundance remained roughly the same southward to Station 18. At the most southerly sampling station (Station 6), abundance

was higher than in the rest of the lake except for the most northern stations (Station 77 and 64). This pattern is not dissimilar from the geographical pattern observed in 1983 for Lake Michigan (Makarewicz 1987). This abundance pattern is attributed mainly to the picoplankton, the Bacillariophyta and the Cyanophyta which all have higher abundances at the northern stations. The higher abundance at Station 6 was caused by the picoplankton. The peak in abundance of the Cryptophyta at Station 41 in 1983 (Makarewicz 1987) was again observed in 1984 but was not as prominent as in 1983. A peak in Chlorophyta at Station 41 was not observed in 1984 as it was in 1983. Cyanophyta were in higher abundance at the northern stations (77 and 64) and at Stations 41-27 (Fig. 12).

Seasonally, the spring and autumn cruises possessed a geographical abundance pattern similar to the mean annual phytoplankton distribution with abundance peaks at the northern (Stations 64 and 77) and southern (Station 6) stations (Fig. 13). Abundances of Bacillariophyta, Cyanophyta and picoplankton peaked at these stations. Only on the 27-29 November cruise did a maximum in abundance not occur at Station 6. The summer cruises did not display the distinctive northern and southern peaks observed in the spring and autumn of 1984. Similar geographical peaks in abundance were observed at the northern and southern stations in 1983 (Makarewicz 1987).

Interestingly, many of the same species had distinctly higher abundances in 1983 and 1984 at the northern and southern stations. Tabellaria flocculosa, Fragilaria crotonensis, Cyclotella comensis, Coelasphaerium naegelianum and picoplankton were more abundant at the northern stations than in the rest of the lake in 1983 and 1984. In addition, Oocystis submarina was abundant in 1984, while Cyclotella comta,

Chroomonas norstedtii and Oscillatoria agardhii had a greater abundance at the northern stations 64 and 77 in 1983. Except for C. comensis, whose ecological affinities are poorly known, the other diatom species more prevalent at Stations 64 and 77 are generally associated with mesotrophic conditions.

Besides picoplankton, the abundance peak at Station 6 in both 1983 and 1984 was attributed to Dinobryon sociale var. americanum and D. divergens. Species of haptophytes prevalent at Station 6 in 1983 were not prevalent in 1984.

The northern stations 64 (depth = 25m) and 77 (depth = 23m) and the southern station 5/6 (mean depth = 50m) are best described as nearshore stations [depths are less than or equal to 50m (Bartone and Schelske 1982)]. The physical and chemical characteristics of the nearshore and the Straits of Mackinac stations differ significantly from the open lake stations (Bartone and Schelske 1982). Thus the differences in phytoplankton abundances observed at the northern and southern stations in this study should be related to known differences in water quality. There is some evidence to support this hypothesis. A comparison of nutrient data from the nearshore and offshore stations indicates that total phosphorus was higher at Station 64 and silica was higher at Station 77 compared to the rest of the lake (Table 14). Station 6 had nutrient levels similar to the rest of the lake.

Temperature may also be a factor in the occurrence of the geographic abundance peaks observed. For example, on 6 and 7 May the higher temperatures and abundances at Stations 6, 64 and 77 correlate well (Fig. 13).

### Indicator Species

Stoermer and Yang (1970), in a comparison of modern and historic records, reported that taxa characteristic of disturbed situations were rapidly increasing in relative abundance in Lake Michigan in the 60's. In the nearshore area, a shift in oligotrophic forms to those which dominate under eutrophic conditions was evident. Occurrence of certain eutrophic species was also evident in offshore waters (Stoermer and Yang 1970).

Dominant diatom species in the offshore waters in 1983 were Cyclotella comensis, C. comta, Tabellaria flocculosa, Fragilaria crotonensis and Melosira italica subsp. subartica. The same five diatoms were dominant in 1984 with the exception of C. comta and the addition of Rhizosolenia eriensis and Cyclotella ocellata (Table 10). In fact, R. eriensis accounted for ~25% of the total biomass of phytoplankton during 1984.

Rhizosolenia eriensis may be an opportunistic species which is able to rapidly develop fairly high abundances when conditions are favorable (Stoermer and Ladewski 1976). Stoermer and Yang (1970) listed R. eriensis with the oligotrophic offshore dominants, which includes C. ocellata, but noted that R. eriensis seemed to occur in greater abundance in areas that have received some degree of nutrient enrichment. Tabellaria flocculosa and F. crotonensis are mesotrophic forms, while the ecological affinities of C. comensis are poorly understood. Cyclotella comensis was formerly found in primarily oligotrophic areas (Stoermer and Stevenson 1979) under some nutrient stress (Stoermer and Tuchman 1979). Compared to the 1983 cruises (Makarewicz 1987), where mesotrophic forms were predominant, the same mesotrophic forms were present in 1984 along with oligotrophic indicators.

The indicator diatom species and the distribution of them (trophic ratio) (Table 15) suggest a eutrophic status for nearshore waters in 1977, while the offshore waters in 1970-71, 1983 and 1984 would be in the oligotrophic-mesotrophic range. With the high mesotrophic/eutrophic ratio in 1970-71 ( $M/E = 8$ ) as compared to 1983 and 1984 ( $M/E = 4$ ), it is tempting to suggest a slightly more mesotrophic status in more recent years. At best, this observation has to be viewed with caution since only one species difference is required to achieve the observed change. The  $M/E$  ratio has to be interpreted conservatively as it is influenced somewhat by the definition of the dominant species (e.g. 1% of biomass) utilized. Nevertheless, the trophic status as determined by indicator species and the  $M/E$  ratio agrees well with the 1976 assessment based on particulate phosphorus concentrations that place the open lake waters of Lake Michigan in the oligotrophic-mesotrophic range (Bartone and Schelske 1982).

#### Historical Changes in Community Abundance

A comparison of abundance trends over the entire lake was not possible because of the lack of comparable offshore data prior to 1983. Figure 14 plots the 1962-63 and the 1976-77 data of Stoermer and Kopczynska (1967a and b) and Rockwell et al. (1980), which are representative of the southern portion of the lake. Only a range of abundance is available for 1962-63, while the mean, standard error and range are plotted for the other data. Because picoplankton were not counted prior to 1983, they are removed from the 1983 and 1984 data presented in Figure 14. Although a mean is not available, it is apparent that abundance increased from 1962-63 to 1976-77. From 1976 to 1983 and 1984, abundance was not significantly different ( $P=0.05$ ). Based on the

classification scheme of Munawar and Munawar (1982), which utilizes the mean phytoplankton biomass as an indicator of trophic status, Lake Michigan would be classified as oligotrophic in 1984. This designation is supported by the trophic ratio and composition of indicator species.

## LAKE MICHIGAN

### Zooplankton

#### Annual Abundance of Zooplankton Groups

Species lists (Table A4) and summary tables of abundance (Table A5) and biomass (Table A6) are in Volume 2 - Data Report. The zooplankton assemblage of 1984 comprised 52 species representing 34 genera from the Calanoida, Cladocera, Cyclopoida, Harpacticoida, Mysidacea and Rotifera. Compared to 1983, reductions of 21% and 24% in numbers of genera and species, respectively, were observed. This difference is mostly attributable to a decrease in number of Cladocera and Rotifera.

The Rotifera possessed the largest number of species (29) and relative abundance (67.5%) followed by the Cladocera (10 species) which accounted for 39.8% of the zooplankton biomass (Table 16). The Rotifera contributed only 2.6% of the total biomass (Table 16). Average density and biomass for the study period was  $59,764 \pm 8,284$  organisms/m<sup>3</sup> (mean  $\pm$  S.E.) (1983 = 69,353) and  $33.2 \pm 4.9$  mg/m<sup>3</sup> (mean  $\pm$  S.E.) (Table 6).

#### Seasonal Abundance and Distribution of Major Zooplankton Groups

The seasonal abundance and biomass pattern were virtually identical (Fig. 15) with a maximum in August. The secondary maximum observed in October of 1983 (Makarewicz 1987) was not observed in 1984. This major difference between 1983 and 1984 is apparent and is probably related to the difference in the seasonal sampling pattern between years. Samples were not taken in September and October of 1984. A sampling pattern including the June-July and September-October period is required to fully evaluate the differences in the seasonal distribution pattern.

Seasonally, abundance and biomass of all groups were higher in August as compared to the early spring and late fall (Figs. 16 and 17). In 1983



a peak in rotifer abundance occurred in October (Makarewicz 1987), which was not observed in 1984 due to a lack of October samples. The high abundance of Cyclopoida, Calanoida, Cladocera and Copepoda nauplii in August of 1984 was not observed in 1983 (Makarewicz 1987).

#### Geographical Abundance and Distribution of Zooplankton Groups

A definite trend of increasing zooplankton abundance occurred from south to north in Lake Michigan (Fig. 18). Zooplankton abundance at the far northern Stations 64 and 77 was higher than in the rest of the lake. Abundances of Rotifera, Cladocera and Copepoda nauplii were all higher at these far northern stations. Biomass, however, was similar southward from Station 77 to Station 18, after which biomass decreases southward (Fig. 19). These patterns were not observed in 1983 (Makarewicz 1987).

Abundance of Diaptomus sicilis was higher in southern Lake Michigan (Makarewicz 1987) in 1983. However, a similar pattern was not evident (Fig. 20) in 1984. Copepodites of Diaptomus averaged a higher abundance in southern Michigan. Similar to 1983 was the increase in Cladocera abundance at the far northern stations (Fig. 19). Abundance of Bosmina longirostris dramatically increased at these stations in 1983 and 1984 (Fig. 21). Also, Eubosmina coregoni, Notholca laurentiae, N. squamula, N. foliacea and Holopedium gibberum all had abundance peaks at the far northern end of the lake in 1983 and 1984 (Fig. 22). Polyarthra vulgaris and P. remata had higher abundances in 1984 only at the northern Stations 64 and 77 (Fig. 22).

#### Common Species

Common Crustacea species (Table 17) were arbitrarily defined as those possessing a relative abundance of  $>0.1\%$  of the total abundance or  $1.0\%$  of

the total biomass. Rotifera species were considered common if they accounted for >1.0% of the total zooplankton abundance or biomass. The number of common species (1983 = 25 species; 1984 = 24 species) and common species composition were essentially the same between 1983 and 1984. Rotifer composition differed with Notholca foliacea, N. laurentiae and Polarthra remata being common in 1984 only, while P. major, P. dolichoptera, Keratella crassa and K. earlinea were common in 1983.

### Historic Changes in Species Composition

#### Crustacea

Numerous recent studies (Williams 1966; Johnson 1972; Gannon et al. 1982a, 1982b; Evans et al. 1980) of the nearshore region of Lake Michigan exist, along with data from as far back as 1927 (Eddy 1927). Several researchers have compared the nearshore with the offshore zooplankton in discussions of eutrophication of the entire lake. Comparisons of the inshore with the offshore stations should be viewed with caution because effects are not necessarily due to eutrophication or fish predation (Evans et al. 1980).

Although no intensive zooplankton studies of the offshore waters of the entire lake basin have taken place, some offshore studies of Lake Michigan zooplankton do exist. Wells (1960, 1970) sampled Crustacea with a number 2 (366µm) net on four dates in June, July and August in 1954, 1966 and 1968 from the offshore region off Grand Haven, Michigan. On six dates (March 1969 to January 1970), Gannon (1975) collected crustaceans with a 64-µm mesh net from the offshore and inshore of Lake Michigan along a cross-lake transect from Milwaukee to Ludington. In September of 1973, northern Lake Michigan was sampled with a 250-µm mesh net (Schelske et al.

1976). Also, Stemberger and Evans (1984) provided abundance data (76-um net) for a few zooplankters from offshore waters of the southeastern Lake Michigan area.

The data of Wells (1960, 1970) and Gannon (1975) are useful but have to be used with caution. A 366-um and a 250-um net are probably quantitative for larger crustaceans but certainly would not be for smaller crustaceans such as Chydorus sphaericus, Bosmina longirostris, Eubosmina coregoni, Ceriodaphnia spp., Tropocyclops prasinus and copepods (Makarewicz and Likens 1979).

The zooplankton populations in Lake Michigan underwent striking size-related changes between 1954 and 1966 (Wells 1970). Species that declined sharply were the largest cladocerans (Leptodora kindtii, Daphnia galeata mendotae and D. retrocurva), the largest calanoid copepods (Limnocalanus macrurus, Epischura lacustris and Diaptomus sicilis) and the largest cyclopoid copepod (Mesocyclops edax). Medium-sized or small species (D. longiremis, H. gibberum, Polyphemus pediculus, Bosmina longirostris, Ceriodaphnia sp., Cyclops bicuspidatus, Cyclops vernalis, Diaptomus ashlandi) increased in number, probably in response to selective alewife predation. After the alewife dieback, M. edax and D. galeata mendotae were still rare in 1968 when the composition of the zooplankton community shifted back toward one similar of 1954 (Wells 1970).

In northern Lake Michigan during September of 1973, predominant species were Daphnia galeata mendotae, D. retrocurva, Limnocalanus macrurus, Diaptomus oregonensis, Eubosmina coregoni and Diaptomus sicilis. Cyclopoid copepods were a minor component of the fauna in 1973 (Schelske et al. 1976).

The changing nature of the zooplankton community of Lake Michigan was evident in 1983. Daphnia galeata mendotae, D. pulicaria and D. retrocurva were the second, third and fourth most abundant cladocerans in the lake (Makarewicz 1987). D. galeata mendotae and D. retrocurva were again the prominent daphnids in 1984 along with the dominant cladoceran Bosmina longirostris. Abundance of Daphnia pulicaria dropped from an average of  $376/\text{m}^3$  in 1983 to  $78/\text{m}^3$  in 1984. In August of 1983, abundances of D. galeata, rare in 1966 and 1968, were half of those in 1954 ( $1,200/\text{m}^3$ ) and three times the 1954 abundance in 1984 (Table 18).

The 1983 abundance of Daphnia retrocurva was similar to the August 1966 abundance rather than to those of 1954 or 1968. However, maximum abundance in October of 1983 ( $3,161/\text{m}^3$ ) was comparable to the 1954 or 1968 observations. Perhaps related to the low abundance of D. retrocurva in August of 1983 was the appearance of the large ( $\sim 2$  mm) (Evans 1985) cladoceran Daphnia pulicaria, which reached a maximum abundance in August. When D. pulicaria dropped in abundance in 1984, D. retrocurva abundance increased to a density comparable to those of 1954 and 1968 (Table 17).

Evans (1985) recently reported that D. pulicaria was first observed in Lake Michigan in 1978. Abundance remained low in southeastern Lake Michigan until 1982 and 1983 when they dominated the offshore summer Daphnia community and at an offshore station southeast of Grand Haven, Michigan. In 1983 this species was the dominant cladoceran in the offshore waters of Lake Michigan from the short and long hauls. Mean station abundance reached  $1,741$  organisms/ $\text{m}^3$  in early August with a maximum of  $6,056/\text{m}^3$ . In 1984, abundance of D. pulicaria dropped to a mean of  $248/\text{m}^3$  from  $1011/\text{m}^3$  in 1983 (Table 18).

The occurrence of Daphnia dubia, a new species observed in 1983, was not confirmed in 1984. In a review of the 1983 material by a different taxonomist, this species was not observed.

The large cladoceran Leptodora kindtii appears to be steadily increasing in abundance since 1954 in Lake Michigan (Table 18). Eubosmina coregoni, B. longirostris and the larger Holopedium gibberum have also increased in abundance since 1954 (Table 18). The increase in H. gibberum was probably real. It is doubtful that this large cladoceran would pass through a 366-um mesh net like that used in Wells (1960, 1970) studies of 1954-68. However, the net employed by Wells' would not have been quantitative for E. coregoni and B. longirostris.

Cyclops bicuspidatus was the dominant cyclopoid in 1983 and 1984 with Diaptomus ashlandi being the dominant calanoid in 1983 (Makarewicz 1987) and D. sicilis in 1984 (Table 17). Abundance of Mesocyclops edax was low in August of 1983 and 1984 compared to 1954, but abundance in early October of 1983 reached a comparable 151 organisms/m<sup>3</sup> (mean station abundance). Diaptomus minutus appears to have decreased in abundance since 1968, while D. oregonensis abundance remained similar to 1954 (Table 19). D. sicilis has increased steadily since 1968. Abundance of Limnocalanus macrurus was lower during August of 1983 than in 1954-68. However, abundance in 1984 was similar to 1954 and 1966. The abundance of Epischura lacustris in August was still low in 1983 and 1984 relative to 1954, but reached 111 organisms/m<sup>3</sup> (mean station abundance) in late October of 1984.

By 1983 and 1984, the large cladocerans, calanoids and cyclopoid copepods, observed by Wells (1970) to have decreased sharply in the early 60's, had increased in abundance to densities similar to those in August

of 1954. In some instances, abundance was not as high in August but was as high at other times of the year. In addition, a new large cladoceran, Daphnia pulicaria, has become established in the offshore waters of Lake Michigan.

The resurgence of larger zooplankton in Lake Michigan is probably related to the sharp decline in the abundance of the planktivorous alewife in 1982 and 1983. The lakewide catch of adult alewives was only 31% of that of 1982 and only 12% of the 1981 catch. Bloater chubs are replacing the alewives and have been experiencing a dramatic increase in abundance since 1970 (Wells and Hatch 1983). Bloaters above ~18 cm in size primarily feed on Mysis and Pontoporeia. Only smaller individuals feed on zooplankton (Wells and Beeton 1963).

#### Rotifera

Rotifer studies reported in the literature are primarily from the nearshore region of the lake. In the nearshore, Keratella cochlearis, Polarthra vulgaris, Kellicottia longispina, Synchaeta stylata and Synchaeta tremula were dominant in 1926-27 (Eddy 1927). Keratella and Polarthra were the dominant genera in 1962 (Williams 1966), while K. cochlearis and P. vulgaris were dominant in 1970 (Johnson 1972). Gannon et al. (1982a) noted that the following rotifers were predominant in 1977: Keratella cochlearis, K. crassa, Conochilus unicornis, Kellicottia longispina, Polarthra vulgaris and P. remata.

Abundance of rotifers in Lake Michigan generally decreased from the nearshore into the offshore (Gannon et al. 1982a, Stemberger and Evans 1984) although the species composition of the nearshore and offshore was relatively similar. In 1983 the predominant offshore rotifers were in descending order: Polarthra vulgaris, Synchaeta sp., Keratella

cochlearis, Polyarthra major, Kellicottia longispina, Keratella crassa, Gastropus stylifer and Colletheca sp. (Makarewicz 1987). The predominant rotifers in 1984 were Keratella cochlearis, Kellicottia longispina, Polyarthra vulgaris and Synchaeta sp. (Table 17). Both the 1983 and 1984 dominant rotifer composition is similar to the nearshore and to Ahlstrom's (1936) offshore observations of predominant species (Keratella cochlearis, Synchaeta stylata and Polyarthra vulgaris).

#### Historical Changes in Zooplankton Biomass

Offshore crustacean zooplankton biomass data is available from 1976 (Bartone and Schelske 1982) for northern Lake Michigan. No information is presented on sampling intensity or technique. A comparison with 1984 (Table 20) reveals that no significant difference in crustacean biomass exists between 1976 and 1984.

Another longer sequence of data is described by Scavia et al. (1986). Except for 1977, 1982, 1983 and 1984, zooplankton samples were primarily from an offshore station (40-m depth) west of Benton Harbor, MI. A comparison of the mean offshore 1984 lake-wide biomass data to Scavia's station indicates good agreement (Fig. 23). From Figure 23, there appears to be no obvious trends in zooplankton biomass.

#### Indicators of Trophic Status

Zooplankton have potential value as assessors of trophic status (Gannon and Stemberger 1978). Rotifers, in particular, respond more quickly to environmental changes than do the crustacean plankton and, therefore, are more sensitive indicators of changes in water quality. Composition of the rotifer community (Gannon and Stemberger 1978) can be used to evaluate trophic status.

In 1983 the six predominant rotifers in descending order of relative abundance were P. vulgaris, Synchaeta sp., K. cochlearis, P. major, K. longispina and C. unicornis, while in 1984 the predominant rotifers were K. cochlearis, K. longispina, P. vulgaris and Synchaeta sp. The 1983 and 1984 rotifer composition suggests an oligotrophic association. A rotifer community dominated by Polyarthra vulgaris, Keratella cochlearis, Conochilus unicornis and Kellicottia longispina has been considered to be an association indicative of an oligotrophic community by Gannon and Stemberger (1978).

The high relative abundance of Diaptomus sicilis and Limnocalanus macrurus (Table 17) and the occurrence of Senecella calanoides, all oligotrophic indicators (Gannon and Stemberger 1978, McNaught et al. 1980), also suggested oligotrophic offshore conditions for the entire lake.

The calanoid/cyclopoid plus cladoceran ratio has been used as a measure of trophic status in the Great Lakes (Gannon and Stemberger 1978, McNaught et al. 1980). Calanoid copepods generally appear best adapted for oligotrophic waters, while cladocerans and cyclopoid copepods are relatively more abundant in eutrophic waters. On the north-south transect, the plankton ratios were high and similar, except at the far north and the southern extreme of the lake (Table 21). This pattern was repeated in 1984 and suggests that a lower quality of water occurred south of Station 18 and north of Station 57. The eutrophic rotifer indicator species Trichocerca pusilla was observed exclusively at Station 6, reinforcing the idea that a lower water quality exists at Station 6. Similarly, Trichocerca multicornis, a eutrophic indicator, was prevalent at northern stations.



The low plankton ratios (0.20 - .41; Table 21) at the far northern end of Lake Michigan (Stations 64 and 77) were very similar to those observed in 1973 at the Straits of Mackinac (Gannon and Stemberger 1978). Gannon and Stemberger (1978) implied that more eutrophic conditions exist within this area of a low calanoid to cladoceran plus cyclopoid ratio. Abundance of the oligotrophic Limnocalanus macrurus and Diaptomus sicilis was significantly lower in these far northern stations, while Eubosmina coregoni and Bosmina longirostris, often associated with more productive conditions, increased at the far northern stations (Fig. 21). In addition, several mesotrophic algal species were more predominant at the northern stations.

Notholca foliacea is often associated with oligotrophic conditions (Gannon and Stemberger 1978). In this study, several indicators suggest that the northern end of Lake Michigan near the Straits of Mackinac has waters associated with more productive conditions. Yet abundance of Notholca foliacea increased at the northern stations. The use of N. foliacea as an oligotrophic indicator has to be viewed with caution.

With a zooplankton abundance between those of Lakes Erie and Huron (Table 6), the presence of an oligotrophic rotifer association, a plankton ratio between those of Huron and Erie, the domination of the calanoids and the fairly abundant presence of the oligotrophic indicator species Diaptomus sicilis and Limnocalanus macrurus, the offshore waters of Lake Michigan in 1984 are best characterized as mesotrophic/oligotrophic. A similar conclusion utilizing zooplankton abundance and species composition was drawn in 1983. Phytoplankton composition and abundance and water chemistry suggest a similar trophic status (This Study).

### Trophic Interactions

Between 1975 and 1984, gradual declines in spring total phosphorus and summer epilimnetic chlorophyll *a* are reported (Scavia et al. 1986). However, long-term changes of phytoplankton and zooplankton biomass are not apparent in this study. Perhaps, the minimal changes observed in chlorophyll *a* are not reflected in the high variability phytoplankton and zooplankton estimates. Scavia et al. (1986) points out that the changes in total phosphorus and chlorophyll *a* are consistent with expectations of nutrient load control.

However, the significant lake-wide changes in zooplankton and phytoplankton composition may not be expected from nutrient control. A species new to the plankton assemblage, Daphnia pulicaria, is at least a sub-dominant organism within the offshore. In addition, Leptodora kindtii, Daphnia galeata mendotae, Diaptomus ashlandi and Cyclops bicuspidatus have returned to and exceeded abundances observed in 1954 during a period of low alewife abundance.

Scavia et al. (1986) suggests that predatory pressure from alewife suppressed large-bodied zooplankton until the early 1980's. Decline of the alewife population as the major forage fish (Jude and Tesar 1985, Wells and Hatch 1983) has been linked to the increasing population of stocked salmonines in Lake Michigan (Stewart et al. 1981, Jude and Tesar 1985). The decrease in alewife abundance has reduced size-selective predation on larger zooplankton allowing larger zooplankton to return (Scavia et al. 1986, Wells 1970, Kitchell and Carpenter 1986).

Table 22 lists correlation coefficients of phytoplankton abundance versus total phosphorus and zooplankton for each cruise. For each cruise, 11 stations covering the entire length of the lake were sampled over a

short period of time. Interpretations of the correlations were as follows: A negative correlation between a zooplankton group and phytoplankton implied grazing pressure on phytoplankton, while a positive correlation between total phosphorus and phytoplankton abundance would suggest an enhancement of phytoplankton abundance due to phosphorus availability. Except for the early winter cruise, correlation of total phosphorus to phytoplankton abundance was weak as compared to Lake Erie (Table 22). Grazing pressure appeared to be particularly heavy during the May series of samples.

As suggested by Scavia et al. (1986), D. pulicaria appears to have a negative impact on phytoplankton abundance especially during mid-August. Interestingly, when Daphnia galeata mendotae is added to the correlation analysis, the correlation coefficient increases from  $-.27$  to  $-.50$  suggesting that D. galeata mendotae is also having a major effect on phytoplankton abundance during August. This would be an added effect in that D. galeata has increased since 1954 apparently in response to decreased selective pressure by the alewife. The calanoids appear to exert grazing pressure in the spring and early winter as opposed to the summer (Table 22).

The causes of the changes in species composition of phytoplankton are much more difficult to evaluate. Changes in herbivore species composition could affect algal species composition. Certain zooplankton feed on a wide variety of algae of different sizes and shapes, and with or without sheaths (Gliwicz 1980, McNaught et al. 1980b, Porter and Orcutt 1980). Other zooplankton are highly selective in the algal types ingested. Cellular forms are ingested more readily than filamentous or spinuous forms and zooplanktonic filtration rates, growth and survivorship are

greater when feeding on cellular forms (Porter 1973, Arnold 1971). Selective grazing and utilization can remove species or reduce population size in the algal community. Alternatively, grazer utilization of an algal species can result in enhancement of primary productivity of that species by increased selection for faster growing genotypes (Crumpton and Wetzel 1982).

In summary, zooplankton community structure is important in determining the responses of algal assemblages to grazing (Bergquist et al. 1985). Small algal taxa increase in abundance when grazed by small zooplankton, but decrease in density when grazed by large zooplankton. Conversely, large phytoplankton become less abundant in the presence of small zooplankton, but increase in density in the presence of large zooplankton (Bergquist et al. 1985). Perhaps the increase in abundance of the large diatom Rhizosolenia spp. during the summer of 1984 is related to increased grazing pressure of large Daphnia.

Nutrient effects can also affect composition of phytoplankton. For example, Asterionella is a successful competitor at high Si/P ratios, Fragillaria can dominate at intermediate ratios and Stephanodiscus grows well when Si/P ratios are low (Kilham and Kilham 1978; Kilham and Tilman 1979; Tilman 1978, 1980). At high Si/P ratios, diatoms can effectively out compete blue-green algae (Holm and Armstrong 1981). Similarly, as silica is reduced and combined nitrogen declines, green algae can compete less effectively with nitrogen-fixing blue-greens (Smith 1983). Effects on phytoplankton composition from both top-down and bottom-up routes are expected but are difficult to separate in this descriptive study.

## LAKE HURON

### Phytoplankton

Species lists (Table A7) and summary tables of abundance (Table A8) and biovolume (Table A9) are in Volume 2 - Data Report. A summary of water chemistry parameters is presented in Table 6.

#### Annual Abundance of Major Algal Groups

The phytoplankton assemblage of 1984 was comprised of 315 species representing 92 genera from eight divisions (Table 23). Compared to 1983, a 4.3% reduction in the number of species and a 4.5% increase in the number of genera were observed.

The annual average phytoplankton density and biovolume were 17,209 cells/mL (19,147 cells/mL; 1983) and  $0.38 \text{ mm}^3/\text{L}$  ( $0.42 \text{ mm}^3/\text{L}$ ; 1983), respectively. Similar to 1983, the Bacillariophyta possessed the largest number of species (156) and biovolume (61.9% of the total, Table 24), while the second largest number of species (64) was observed for the Chlorophyta (Table 24). Although the relative biovolume of the Cryptophyta in 1984 (9.1%) was similar to 1983 (8.3%), their relative importance dropped from second to third (Table 24). The Chrysophyta accounted for the second highest biovolume (9.45%). Highest overall densities were attained by the picoplankton (83.9% of the total). Both the Cyanophyta and the Chlorophyta had lower average biovolumes in 1984 than in 1983, while Pyrrophyta biovolume increased (Table 24).

#### Seasonal Abundance and Distribution of Major Algal Groups

Seasonally, abundance (cells/mL) and biovolume ( $\text{mm}^3/\text{mL}$ ) increased from April to a maximum (33,355 cells/mL) in early July (Fig. 24b). A secondary maximum in abundance (19,663 cells/mL) was observed in August,

due to picoplankton. A secondary peak was not observed in the biovolume seasonal distribution (Fig. 24a) because of the low biovolume of the picoplankton. Samples were not taken during the late summer and early fall. Abundance was low in November and decreased into early December (11,388 cells/mL). Abundance increased slightly in January but returned to December levels in February. Abundances in the early spring, fall and winter were not significantly different. Also, biovolume was not significantly different between the early spring, fall, winter and August (Fig. 24a).

Considering biovolume, the Bacillariophyta were dominant throughout the study period accounting for as much as 72% but never less than 44% of the phytoplankton biovolume (Fig. 25). The large drop in the relative importance of diatoms in August of 1983 (to ~30% of the total biovolume, Makarewicz 1987) was not observed in 1984. A drop to 47% of the biovolume did occur in August. The occurrence of a bloom of Rhizosolenia eriensis in August of 1984, not observed in 1983, was the major cause of the dominance of the diatoms during the summer (Table 25). With the decrease in the relative biovolume of diatoms, a seasonal succession of Pyrrophyta peaking in July, Cryptophyta in early August, and Chrysophyta in August is evident. Diatoms regained their spring predominant position by February (Fig. 25). Cryptophyta appeared to increase in importance during the study period accounting for 18% of the total biovolume in the late autumn and winter samples.

#### Geographical Abundance and Distribution of Major Algal Groups

In 1983 the mean phytoplankton abundance for the sampling period generally decreased from north to south to ~Station 15, where abundance increased and then decreased slightly southward (Fig. 26) (Makarewicz

1987). In 1983 Asterionella formosa, Cyclotella comensis, C. comta, and C. ocellata all had a higher biomass at Station 61 than at other stations (Makarewicz 1987). A similar algal geographical distribution was not observed during the 1984-85 sampling period (Fig. 27). There was no obvious pattern on a cruise basis either (Fig. 28). Not one common algal species had an abundance maximum at the northern stations in 1984. Although not likely, this difference may be attributed to the sampling patterns between 1983 and 1984. In 1983 six of the seven cruises sampled the same stations, while in 1984 only 50% of the cruises sampled the same stations (Table 4). This sampling pattern apparently did not affect zooplankton data. Similar to 1983, zooplankton populations were higher at Station 61 in 1984.

#### Regional and Seasonal Trends in the Abundance of Common Taxa

Common species (Table 26) were arbitrarily defined as those possessing a relative abundance of  $>0.1\%$  of the total cells or  $>0.5\%$  of the total biovolume. Ninety-four percent of the common species observed in 1984 were also common species in 1983. Ten percent of the common species observed in 1983 were not common in 1984 (Table 27) (Makarewicz 1987).

The causes of these differences are difficult to evaluate. Natural annual variability of plankton populations in the lake has never been evaluated and cannot be evaluated until a more extensive data set exists. Seasonal sampling variability exists between 1983 and 1984 and is the most probable cause for the species differences observed. For example, both Oscillatoria minima and Stephanodiscus minutus were common in 1984 because of their high density in the winter of 1984-85. Winter samples were not available in 1983-84.

Because of the similarity of the 1984 common species list to the 1983 list, a species by species description of autecology and regional and seasonal trends are not warranted here and can be referred to in Makarewicz (1987). Only new common species are discussed below.

#### Bacillariophyta

##### Cyclotella stelligera (Cl. and Grun.) V.H.

This species is a common offshore dominant in Great Lakes phytoplankton assemblages (Stoermer and Kreis 1980). It is apparently intolerant of highly eutrophic conditions in the natural environment (Stoermer and Kreis 1980). In 1971 Munawar and Munawar (1982) reported C. stelligera to be a common lakewide species (>5% of the phytoplankton biomass). In southern Lake Huron during 1974, mean abundance was 54 cells/mL with a maximum of 720 cells/mL in July (Stoermer and Kreis 1980). At a single offshore station in southern Lake Huron, Lin and Schelske (1978) observed a maximum of 762 cells/mL in late July with an average for the sampling period (March-December 1975) of 111 cells/mL. Offshore average abundance and maximum abundance in 1980 were 10.9 cells/mL and 60.7 cells/mL, respectively (GLNPO Data Base). Abundance in 1983 was only 6.5 cells/mL (Makarewicz 1987), while in 1984 average abundance was 25.3 cells/mL with a maximum of 267 cells/mL. The lower mean abundance observed in 1983 and 1984 is probably caused by the lack of sampling in the month of July in both years, when this species is historically dominant. Abundance was low during the spring, fall and winter of 1984 (Fig. 29a). The population did increase by the 5-7 July sampling date (mean station abundance = 123 cells/mL) but did not reach the higher abundances historically observed later in July.



Stephanodiscus alpinus Hust. (= S. astrea var minutulus)

Munawar and Munawar (1979) did not list this species as common in 1971. Similarly, abundance was generally low in 1974 (mean = 2.6 cells/mL) (Stoermer and Kreis 1980), in 1975 (Lin and Schelske 1978), in 1980 (mean = 0.1 cells/mL) (GLNPO Data Base) and in 1983 (mean = 0.25 cells/mL) (Makarewicz 1987). Abundance was also low in 1984 (mean = 1.5 cells/mL), but biovolume represented 0.91% of the total biovolume, thereby qualifying it as a common species (Table 26). In 1984 seasonal abundance peaked in early July (Fig. 29b) and was low (< 2 cells/mL) during the remainder of the sampling period.

This species is a common minor element of the Lake Huron phytoplankton assemblage. It appears to be favored by low levels of eutrophication, but it is not tolerant of extreme levels of perturbation (Stoermer and Kreis 1980).

Stephanodiscus minutus Grun. (= S. minutulus)

S. minutus is generally considered to be a fall or winter blooming species in mesotrophic or eutrophic lakes (Stoermer and Ladewski 1976). It was not common in 1971 (Munawar and Munawar 1979) and possessed a low abundance in 1974 (mean = 7.5 cells/mL) (Stoermer and Kreis 1980), in 1975 (mean = 4.2 cells/mL) (Lin and Schelske 1978), in 1980 (mean = 4.2 cells/mL) (GLNPO Data Base) and in 1983 (mean = 2.56 cells/mL) (Makarewicz 1987).

In 1984, average density was 19.4 cells/mL with a maximum density of 84 cells/mL. Seasonal abundance was low during the summer (< 6 cells/mL), was higher during spring and autumn (~25 cells/mL) and peaked at 63 cells/mL in February of 1985 (Fig. 29c). This species is a winter

species. The low abundances historically observed are related to the lack of winter sampling.

## Chlorophyta

### Cosmarium sp.

Abundance of Cosmarium was low in 1971 (Munawar and Munawar 1979), 1974 (Stoermer and Kreis 1980), 1975 (Lin and Schelske 1978), 1980 (GLNPO Data Base), 1983 (Makarewicz 1987) and even in 1984 (this study). Because of its relatively high individual biovolume, it qualifies as a common taxon (Table 26). Abundance peaks were evident in early July and early winter (Fig. 29d).

## Cryptophyta

### Cryptomonas rostratiformis Skuja

Mean abundance of this species was low (0.8 cells/mL). However, the high biovolume of the individual cell causes it to be a common species in 1984. C. rostratiformis apparently was not observed by Munawar and Munawar (1979), Stoermer and Kreis (1980) or Lin and Schelske (1978) in Lake Huron. In 1983 abundance was low (mean = 0.35 cells/mL). A maximum of 8 cells/mL was observed with a mean of 0.8 cells/mL in 1984 (Table 26). Seasonal abundance showed a great deal of variability, perhaps because of the low abundance.

## Cyanophyta

### Oscillatoria minima Gickl.

Many of the previous workers (Munawar and Munawar 1979, Stoermer and Kreis 1980, Lin and Schelske 1978) on Lake Huron did not identify all forms of Oscillatoria to the species level. Average abundance in 1983 and 1984 was 2.9 (Makarewicz 1987) and 17.3 cells/mL, respectively. Maximum

abundance was 335 cells/mL at Station 45 on 3 August 1984. Seasonal abundance was bimodal with a maxima in mid-summer and winter (Fig. 30).

#### Vertical Distribution

On 15 August 1984, a series of vertical phytoplankton samples were taken at two stations (Stations 15 and 37). The abundance increase with depth at Station 37 can be primarily attributed to an increase in picoplankton (Fig. 31). In general, non-picoplankton abundance did not increase with depth with the exception of Cyclotella ocellata and C. kuetzingiana var. planetophora (Fig. 31). There was no correlation between the abundance increase and temperature (Fig. 31).

At Station 15, phytoplankton samples were taken to a depth of 30m compared to 20m at Station 37. An increase in picoplankton, as well as Bacillariophyta and Chrysophyta, was evident. The abundance increase in these groups correlated with the decrease in temperature associated with the metalimnion (Fig. 32). Cyclotella comensis, C. ocellata and Tabellaria flocculosa were responsible for the diatom abundance increases, while Dinobryon sociale and D. divergens were the primary causes for the Chrysophyta increase with depth (Fig. 32). A similar vertical distribution pattern was observed in Lake Michigan in 1984 (This Study). Brooks and Torke (1977), Mortonson (1977) and Bartone and Schelske (1982) have reported sub-surface maximum in the Great Lakes. Reasons for the existence of the layer are not clear and are apparently complex, encompassing physical, chemical and biological factors (Bartone and Schelske 1982).

### Winter Cruises

Biomass and abundance were low during the winter and not significantly different from the autumn and spring values (Fig. 24). As during the non-winter season, the Bacillariophyta (58.2% of the total biovolume) was the dominant division. However, the Chrysophyta, which were second in importance during the entire sampling period (9.5% of the total biovolume), represented only 0.46% of the total biovolume during the winter. Similar to the Lake Michigan winter assemblage, the importance of the Cryptophyta increased by a factor of greater than three from the non-winter (5.7% - 7.1% for the entire sampling period) to the winter period (17.8%).

Fragilaria crotonensis (mean = 65.4 cells/mL) and Stephanodiscus minutus (mean = 54.1 cells/mL) were the dominant diatoms during the winter period. Abundance of S. minutus was high only during periods of cooler water temperatures (Fig. 29c). Because of the high winter abundance, it became a common species for the year (Table 26). Similarly, Fragilaria intermedia var. fallax, Cryptomonas pyrenoidifera and Oscillatoria minima became common species for the year (Table 26) by virtue of their higher abundance or secondary maxima (Fig. 30) during the winter.

Other major winter diatoms, Cyclotella comensis and Tabellaria fenestrata were common species (Table 26) during the non-winter period. Common winter, as well as non-winter, species of Cryptophyta and Cyanophyta were Gomphosphaeria lacustris, Rhodomonas minuta var. nannoplanktica (1.19% of the total cells-winter) and Cryptomonas erosa (5.30% of total biovolume-winter).

### Historical Changes in Species Composition

The literature pertaining to phytoplankton of the offshore waters of Lake Huron is sparse. Fenwick (1962, 1968) published some qualitative data, and Parkos et al. (1969) listed species observed. Quantitative data from a single offshore station in 1971 exists (Munawar and Munawar 1982, Vollenweider et al. 1974) and preliminary data covering 21 stations in 1971 are partially analyzed (Munawar and Munawar 1979). Stoermer and Kreis (1980) reported on an extensive sampling program in southern Lake Huron including Saginaw Bay during 1974 and provided an extensive bibliography on Huron algal research. Lin and Schelske (1978) reported on a single offshore station sampled in 1975. An intensive study of the entire lake basin was performed in 1980 (Stevenson 1985), but only a few offshore stations were sampled.

Since 1971 diatoms have been the dominant division. Dominant diatoms in 1971 included species of Asterionella formosa, A. gracillima, Cyclotella comta, C. glomerata, C. ocellata, C. michiganiana, Melosira islandica and M. granulata. In addition, species such as Fragilaria crotonensis and Tabellaria fenestrata were common, while cryptomonads, such as Rhodomonas minuta and Cryptomonas erosa, contributed very heavily during different seasons.

The following similar common diatoms (>0.1% of the total cells) were observed in 1974, 1983 and 1984: Asterionella formosa, Cyclotella comensis, C. michiganiana, C. ocellata, Fragilaria crotonensis, Tabellaria fenestrata, I. flocculosa var. linearis and Rhizosolenia sp. Synedra filiformis was present in 1983 and 1984 but was not as common as in the 1974 southern Lake Huron plus Saginaw Bay data. The lower abundance of C. stelligera in 1983 (Makarewicz 1987) and 1984 compared to 1971 (Munawar

and Munawar 1979), 1974 (Stoermer and Kreis 1980) and 1975 (Lin and Schelske 1978) was caused by the lack of sampling during mid and late July when this species is dominant.

Both Cryptomonas erosa and Rhodomonas minuta var. nannoplanktica were dominant in 1971, 1974, 1983 and 1984. Numerically dominant chrysophytes in 1971 were Dinobryon divergens and Chrysosphaerella longispina. In 1983 and 1984, these two species were common along with D. cylindricum and D. sociale var. americanum (Table 26). Haptophytes were also numerically abundant. In general, the diatom Synedra filiformis decreased in abundance after 1974, while D. cylindricum and D. sociale var. americanum have increased in abundance. In general, species composition of common offshore algae has changed little since 1971.

#### Picoplankton

Picoplankton abundance in 1984 (mean = 14,396; maximum of  $3.5 \times 10^4$  cells/mL) was not dissimilar from 1983 (mean = 19,343; maximum of  $6.3 \times 10^4$  cells/mL). On a numerical basis, the picoplankton represented 83.9% of the total cells in 1984 but because of their small biomass, only 1.6% of the total biovolume. Their relative numerical dominance in 1984 was comparable to 1983 (86.6%). Prior to the 1983 study (Makarewicz 1987), other researchers have not routinely reported on this group of organisms.

#### Indicator Species

Dominant diatoms in Lake Huron in 1983 and 1984 were Rhizosolenia sp. (R. eriensis in 1984), Tabellaria flocculosa (biomass) and Cyclotella comensis (numerically). Four species of Cyclotella (C. comensis, C. comta, C. kuetzingiana var. planetophora and C. ocellata) represented 9.4% of the total biomass in 1983 (Makarewicz 1987). In 1984 the same four

species plus Cyclotella stelligera accounted for 6.63% of the total biomass (Table 26). R. eriensis is often grouped with oligotrophic offshore dominants even though it may occur in greater abundance in areas receiving some degree of nutrient enrichment (Stoermer and Yang 1970). Except for C. comensis, whose ecological affinities are poorly understood (Stoermer and Kreis 1980), these species are associated with oligotrophic or mesotrophic conditions. Tabellaria flocculosa is commonly associated with mesotrophic conditions (Tarapchak and Stoermer 1976).

Dominant chrysophytes included Dinobryon sociale var. americanum, D. divergens and D. cylindricum, which are often associated with several small members of the genus Cyclotella (Schelske et al. 1972, 1974) included in the classical oligotrophic diatom plankton association of Hutchinson (1967). Dominant cryptophytes, cyanophytes and dinoflagellates were Rhodomonas minuta var. nannoplanktica, Cryptomonas erosa, picoplankton and Ceratium hirundinella.

Because of the limited number of studies of the Lake Huron offshore phytoplankton assemblage, there was also a limited basis for evaluating the long-term effects of eutrophication. The ratio of mesotrophic to eutrophic species in Lake Huron has not changed since 1971 (Table 28). This suggests that the trophic status of the lake has not changed. Because the trophic ratio has not been extensively used, interpretations of the trophic ratio have to be carefully considered. For example, the lack of change in the ratio in Lake Huron may simply represent a lack of sensitivity in the ratio. However, interpretations using the trophic ratio in collaboration with other indicators suggest interpretations of the trophic ratio parallel the other indicators.

Those studies available (Munawar and Munawar 1979, Nicholls et al. 1977a, Schelske et al. 1972, 1974) indicate that the waters of northern Lake Huron generally contain phytoplankton assemblages indicative of oligotrophic conditions. The designation of the offshore waters of southern Lake Huron as oligotrophic based on phytoplankton composition in 1983 and 1984 is not unlike the trophic status suggested by Stoermer and Kreis (1980) for the offshore waters of southern Lake Huron in 1974. This agrees well with the trophic status as determined by the biomass classification scheme of Munawar and Munawar (1982). With a mean biomass of  $0.38 \text{ g/m}^3$  and  $0.42 \text{ g/m}^3$  for 1983 and 1984, respectively, Lake Huron would be classified as oligotrophic.

#### Historical Changes in Community Abundance and Biomass

Some quantitative phytoplankton data exist for the offshore waters of Lake Huron from at least 1971. The collections of Stoermer and Kreis (1980) were from 44 stations in southern Lake Huron and Saginaw Bay. Lin and Schelske (1978) collected from one offshore station in 1975. In both studies, phytoplankton were concentrated on millipore filters rather than by the settling chamber procedure used in the 1980 (GLNPO Data Base), 1983 (Makarewicz 1987) and 1984 studies. Thus, data sets are not strictly comparable.

Munawar and Munawar (1982) collected with a 20-m integrating sampler from April to December of 1971. Because Utermöhl's (1958) procedure for enumeration of algae was employed, these data were directly comparable to the 1980, 1983 and 1984 data sets. Unfortunately, biomass data for only one offshore station of Lake Huron was available for 1971 (Munawar and Munawar 1979). Phytoplankton biomass between 1971, 1980, 1983 and 1984 was not significantly different (Fig. 33). The consistency of the



mesotrophic-eutrophic ratio through time and the occurrence of oligotrophic and mesotrophic indicator species suggest little change in the trophic status of the offshore waters of Lake Huron.

## LAKE HURON

### Zooplankton

#### Annual Abundance of Zooplankton Groups

Species lists (Table A10) and summary tables of abundance (Table A11) and biomass (Table A12) are in Volume 2 - Data Report. The zooplankton assemblage of 1984 comprised 53 species representing 31 genera from the Amphipoda, Calanoida, Cladocera, Cyclopoida and Rotifera. The diversity of species was similar to 1983 (58 species, 33 genera).

The Rotifera possessed the largest number of species (31) and relative abundance (56.0%) followed by the Calanoida and Cyclopoida. The Copepoda nauplii accounted for 18.6% of the total zooplankton abundance (Table 29). The Calanoida (42.0%) followed by the Cladocera (27.5%) contributed the most biomass to the zooplankton community. Rotifera represented only 2.5% of the zooplankton biomass. Average density and biomass were  $55,369 \pm 7,176$  (mean  $\pm$  S.E.) organisms/m<sup>3</sup> (46,230 - 1983) and  $27.3 \pm 2.3$  (mean  $\pm$  S.E.) mg/m<sup>3</sup> (Table 6).

#### Seasonal Abundance and Distribution of Major Zooplankton Groups

Seasonally, the abundance and biomass were essentially identical (Fig. 34) with a maximum in August. This pattern was similar to that of Lake Michigan in 1984 (Fig. 16). A comparison to 1983 was not possible because of the lack of samples in the spring and summer (Makarewicz 1987). Except for the nauplius stage of the Copepoda, abundance of the major zooplankton groups was highest in August as compared to the spring and late autumn samples (Fig. 35). Nauplii abundance was high throughout the year with a general trend of decreasing abundance towards the winter. A similar pattern was observed with biomass distribution with the exception of the Calanoida. Calanoid biomass did not decrease markedly in the late

fall as compared to other groups (Fig. 36). Growth of the individual Calanoids, even with a decreasing abundance, kept Calanoida biomass high.

### Common Species

Common Crustacea species (Table 30) were arbitrarily defined as those possessing a relative abundance of  $>0.1\%$  of the total zooplankton abundance or  $1.0\%$  of the total biomass. Rotifera species were considered common if they accounted for  $>1.0\%$  of the total zooplankton abundance or biomass. The number of common species were identical in 1983 (22) (Makarewicz 1987) and 1984 (22). Some differences in common species composition were evident. Polyarthra remata, Notholca squamula, and Leptodora kindtii were common in 1984 but not in 1983. Even though the cladoceran Leptodora kindtii was not abundant in 1984, it was a common species because of its high biomass per organism. In 1983 biomass was not evaluated in the designation of common species. Daphnia retrocurva, D. schodleri and D. catawba were common in 1983 but not in 1984. D. catawba was observed only in long hauls in 1983, while D. schodleri was not observed at all in 1984.

### Changes in Species Composition

#### Crustacea

Crustacean studies of the offshore waters of the Lake Huron basin are few in number. Patalas (1972) sampled 51 stations including Saginaw Bay in August of 1968 with a 77- $\mu$ m mesh net. In 1971 eleven stations on a transect from the Straits of Mackinac to the origin of the St. Clair River were sampled from May to November with a 64- $\mu$ m net (Watson and Carpenter 1974). A 64- $\mu$ m mesh net was used to sample ~18 stations on eight dates from April to October of 1974 in southern Lake Huron including Saginaw Bay

(McNaught et al. 1980a). The 1980 study of Evans (1983, 1986) included stations mostly from the nearshore rather than the offshore. The 1983 sampling cruises included 10 stations sampled (64-um mesh net) for each of the three sampling dates between August and September. In 1984 eight stations on five cruises (64-um mesh net) from May-December 1984 were sampled.

In August of 1968, calanoids were dominated by Diaptomus sicilis, D. ashlandi and D. minutus (Patalas 1972). These same three species were predominant in 1971, 1974/75, 1983 and 1984 with the addition of Diaptomus oregonensis in 1983 and 1984 (Table 31). Abundance of Diaptomus ashlandi and Diaptomus sicilis appears to have increased since 1971 (Table 31). The 1974 D. minutus abundance was higher than either the 1971, 1983 and 1984 samples. However, the 1971, 1983 and 1984 data were only from offshore sites, while 1974 data included samples from the eutrophic waters of Saginaw Bay. The oligotrophic indicator species, Limnocalanus macrurus, appears to be decreasing in abundance (Table 31).

In 1971, 1974/75 and 1983, the dominant cyclopoid was Cyclops bicuspidatus thomasi (Table 31). Tropocyclops prasinus mexicanus increased in abundance from 1971 to 1983. However, a notable decline occurred from 1983 ( $577/m^3$ ) to 1984 ( $21/m^3$ ), which may be related to the differences in the timing of the fall sampling in these two years. Mesocyclops edax appears to have increased in abundance (Table 31) from 1971 to 1983. Abundance was lower in 1984 than in 1983. Cyclops vernalis, often associated with eutrophic conditions in Lake Erie, was higher in abundance in the 1974 data. This higher abundance may again have been due to the inclusion of the eutrophic of Saginaw Bay stations in the 1974 data set.

Dominant cladoceran species in August of 1968 were Bosmina longirostris and Holopedium gibberum. Similarly, H. gibberum, B. longirostris and Eubosmina coregoni were dominant in the August-October period in 1974. Comparison of the 1971 and 1984 August data suggests decreases in abundance of B. longirostris and H. gibberum.

Quantitative data on species of daphnids were not available for 1971, but Daphnia retrocurva, Daphnia galeata mendotae and D. longiremis were commonly found in Lake Huron (Watson and Carpenter 1974). The dominant daphnid species in 1983 and 1984 was D. galeata mendotae.

Evans (1985) recently reported that Daphnia pulicaria was a new species dominating the Lake Michigan zooplankton assemblage. In 1983 in Lake Huron, D. pulicaria was observed to be the third most important cladoceran, while in 1984 it dropped to fifth in rank abundance (Table 30). Mean station abundance increased from north to south with a mean density of 431 organisms/m<sup>3</sup> for stations south of Saginaw Bay in 1983. In 1984, abundance never reached the levels of 1983 (Fig. 37).

D. catawba was first reported in waters of Lake Huron in 1983 (Makarewicz 1987). This species was not considered to be either a common or a less common species of the Great Lakes (Balcer et al. 1984). It appeared exclusively in the long hauls from Lake Huron in 1983. A maximum abundance of 1,610 organisms/m<sup>3</sup> was observed in August at Station 12. It was not observed in 1984.

Bythotrephes cederstroemi was observed in Lake Huron for the first time in the long haul of 1984. This European invader was first observed in the Great Lakes in Lake Ontario in 1985 (Lange and Cap 1986). It is a conspicuous species in the plankton of European oligotrophic lakes.

## Rotifera

Stemberger et al. (1979) collected rotifers with a Niskin bottle at 5-m intervals to 20m followed by 10-m intervals to the bottom of the lake at a number of offshore and nearshore areas. Samples were pooled and filtered through a 54-um mesh net on the vessel. The greatest abundance of rotifers in Lake Huron in 1974 occurred in late spring and early summer (Stemberger et al. 1979), a period in which no samples were taken in 1983 and 1984. Comparison of the August-October samples suggested the following between the 1974, 1983 and 1984 data sets; abundant rotifer species in both studies were Conochilus unicornis, Polyarthra vulgaris, Keratella cochlearis and Kellicottia longispina; C. unicornis was the dominant rotifer in 1983; and Keratella cochlearis was dominant in 1974 (Table 30).

Evans' (1986) study of mostly nearshore areas suggests a difference in dominant rotifer species between the offshore and nearshore waters. Dominant rotifer species in this study included in descending rank: Keratella cochlearis, Kellicottia longispina, Synchaeta sp. and Conochilus unicornis. Polyarthra vulgaris and Conochilus unicornis, which were dominant in the offshore waters in 1974, 1983 and 1984, were less abundant in the nearshore waters.

These differences in horizontal distribution of zooplankton are expected in Lake Huron and are affected by the physical limnology of the lake (McNaught et al. 1980a). For example in the warmer inshore areas, cladocerans grow best, while calanoids tend to be found in offshore waters (McNaught et al. 1980a). Nearshore waters are also influenced by the movement of the zooplankton-rich eutrophic waters of Saginaw Bay into the nearshore zone south of the Bay. In general, inshore zooplankton

densities are greater than offshore densities (McNaught et al. 1980a). Similarly, abundance and species composition of rotifers increase and differ in the shallow more productive waters of the western basin of Lake Erie (Fig. 62).

#### Geographical Abundance and Distribution of Zooplankton Groups

The mean station zooplankton abundance was higher in the northern half than in the southern half of Lake Huron (Fig. 38) due primarily to higher rotifer abundance in the north. A similar pattern was observed in 1983 (Makarewicz 1987). With a biomass comparison, no obvious difference between the northern and southern half of the lake was evident (Fig. 39). Cyclopoida and Cladocera abundance was relatively similar along the north-south axis. The Calanoida and nauplius stage of the Copepoda had a geographical distribution pattern similar to the Rotifera with increasing abundance from Station 61 to 45, descending abundance from Station 45 to 27 and 12, and increasing abundance southward (Fig. 39). McNaught et al. (1980a) observed abundance increases of the cyclopoid copepodites, C. bicuspidatus and I. prasinus, north to south in southern Lake Huron. In 1983 rotifers also decreased in abundance from north to south to Stations 9 and 6 where a slight increase was evident.

The 1983 and 1984 data (Figs. 37 and 39) suggest a trend of increasing total zooplankton abundance from Station 12 northward with the exception of Station 32 in 1983. Station 32, located northeast of the mouth of Saginaw Bay, would appear to be too far offshore to be influenced by the higher abundances in the Bay. However, Stoermer and Kreiss (1980) have observed midlake stations in southern Lake Huron to be affected by populations of phytoplankton from Saginaw Bay in 1974. Although the transport of eutrophication-tolerant algal populations into Lake Huron

from Saginaw Bay has been mitigated in recent years (Stoermer and Theriot 1985), the mechanism of transport still exists and thus the transport of zooplankton could still take place from Saginaw Bay.

A number of zooplankton species possessed horizontal distributions that varied along the north-south axis. These differed between 1983 and 1984. In 1983 Diaptomus minutus abundance was lower in the northern portion of the lake, while Daphnia retrocurva had a maximum limited to the far northern stations. Abundance of both Conochilus unicornis and Kellicottia longispina decreased from north to south. Holopedium gibberum had a higher abundance north of Saginaw Bay, while Mesocyclops edax abundances were higher south of Saginaw Bay. Cyclops bicuspidatus thomasi was more abundant at the far northern stations than in the rest of the lake (Makarewicz 1987).

In 1984 Diaptomus sicilis, the copepodite of Mesocyclops, Notholca squamula, Polyarthra vulgaris and Synchaeta sp. had abundances that were higher in southern Lake Huron (Fig. 41). Mesocyclops edax adults did not have a higher abundance in southern Lake Huron as in 1983 (Makarewicz 1987). However, juveniles of Mesocyclops were higher in the southern Lake Huron (Fig. 41). Similar to 1983, abundances of Holopedium gibberum, Kellicottia longispina and Conochilus unicornis were higher in northern Lake Huron (Table 32), while Diaptomus minutus was lower in the northern half of the lake. A similar north-south distribution of algal populations was not observed in 1984.

#### Indicators of Trophic Status

The calanoid/cyclopoid plus cladoceran ratio (the plankton ratio) has been employed as a measure of trophic status in the Great Lakes (Gannon and Stemberger 1978, McNaught et al. 1980a). Calanoid copepods generally



appear best adapted for oligotrophic conditions, while cladocerans and cyclopoid copepods are relatively more abundant in eutrophic waters. Using this ratio, McNaught et al. (1980a) identified the offshore waters of southern Lake Huron to have a higher quality water than the nearshore waters. Because the 1983 and 1984 samples were all from the offshore, no such comparison could be made. However, the 1984 plankton ratio was high and variable from north to south (Table 33). A comparison of the 1983 and 1984 mean phytoplankton ratio suggests a lower quality of water at Stations 6 and 9 and perhaps at Station 61. Water chemistry data suggests these southern stations have higher chloride, sulfate, total phosphorus and turbidity levels and lower silica levels than the rest of the lake (Fig. 42).

Station 61 might be influenced by waters from Lake Michigan. The plankton ratio at Station 61 in Lake Huron is comparable more to northern Lake Michigan than the rest of Lake Huron (Table 34). The physical transport of plankton populations by water currents from Lake Michigan into Lake Huron through the Straits of Mackinac has been demonstrated (Schelske et al. 1976).

Species considered to be indicators of eutrophic waters were rare compared to the western basin of Lake Erie and restricted to extreme southern Lake Huron (Station 6) (Filinia longiseta [ $6.6/\text{m}^3$ ], Trichocerca multicornis [ $12.3/\text{m}^3$ ]) or not detected (Brachionus spp.). The rotifer community in 1983 and 1984 was dominated by Polyarthra vulgaris, Keratella cochlearis, Conochilus unicornis and Kellicottia longispina. This association has been considered to be indicative of an oligotrophic lake (Gannon and Stemberger 1978). The offshore abundances of Holopedium gibberum, Conochilus unicornis and Kellicottia longispina were greater

north of Saginaw Bay than south of it (Table 32) suggesting better water quality in northern Lake Huron. Holopedium gibberum has been reported as an indicator of oligotrophic lakes in Sweden (Pejler 1965) but was widely distributed in both oligotrophic and eutrophic waters in the Laurentian Great Lakes region (Gannon and Stemberger 1978).

The low zooplakton abundance, compared to those of Lakes Erie and Michigan (Table 6), the presence of the oligotrophic rotifer association, the domination of the calanoids, and the fairly abundant presence of the oligotrophic Diaptomus sicilis (McNaught et al. 1980a) suggest oligotrophic offshore waters for Lake Huron in 1983 and 1984.

#### Historical Trends in Abundance

Offshore crustacean zooplankton data collected with similar mesh size nets (64  $\mu$ m) exist for Lake Huron. The 1970 study (Watson and Carpenter 1974; 88 collections) sampled the whole lake, while the 1974/75 work (McNaught et al. 1980a; 46 collections) was from southern Lake Huron. A comparison of the cruise averages for Crustacea (excluding nauplii) (Fig. 43) suggests an increase in abundance from 1970 to 1974 and 1983 followed by an abundance drop in 1984. However, an ANOVA indicates that the means are not significantly different. A similar conclusion of no change in trophic status since 1970 was reached with phytoplankton abundance.

Stemberger et al. (1979) collected Rotifera samples from 44 stations in southern Lake Huron in 1974. Samples were taken with a Niskin bottle at 5-m intervals to 20 m and at 10-m intervals below that. After collection, samples were immediately pooled and filtered through a 54- $\mu$ m net. In 1983 (Makarewicz 1987) and 1984, a vertical tow (64- $\mu$ m net) was taken from 20 m to the surface. Both studies are not directly comparable in that Stemberger's et al. (1979) work represented the entire water

column, while the 1983 and 1984 studies were basically samples from the epilimnion. The 1974 and 1984 sampling periods are not significantly different. A comparison of mean station seasonal abundance suggests that the spring and autumn abundance in 1983 and 1984 was lower than in 1974 (Fig.44). Also, abundance of major species was lower in 1983 and 1984 than in 1974 (Table 35). This difference in abundance is related to two things: (1) Stemberger et al. (1979) used a smaller meshed net which gives a more accurate quantitative sample and thus a higher abundance (Likens and Gilbert 1970); and (2) two different segments of water are being sampled and compared. For example, Makarewicz and Likens (1979) demonstrated higher abundances and different species composition in the hypolimnion as compared to the epilimnion of Mirror Lake, New Hampshire.

#### Trophic Interactions

Within the offshore, there appears to be few changes that could be attributed to nutrient control. Phytoplankton biomass and zooplankton abundance of the offshore waters of Lake Huron in 1971, 1980, 1983 and 1984 are not significantly different. In general, offshore species composition of phytoplankton has changed little since the early 70's. However, there has been a significant lake-wide change in species composition of zooplankton. Prior to 1983, there are no records of Daphnia pulicaria in Lake Huron. In 1983 and 1984, this species ranked third and fifth in abundance in Lake Huron, respectively. The appearance of the large D. pulicaria is generally attributed to a release from size-selective predation of forage fish in Lake Michigan (Scavia et al. 1986, This Study) and Lake Erie (This Study). Daphnia pulicaria abundance is correlated with decreased phytoplankton abundance in 1984 (Table 36), which suggests an additional grazing pressure on phytoplankton stocks in

Lake Huron. This may lead to changes in phytoplankton abundance and composition (See Discussion in Lake Michigan on Trophic Interactions).

A top-down effect on zooplankton is likely in Lake Huron. A careful examination of the time trends in the forage fish base of Lake Huron similar to what was done on Lake Erie (This Study) would provide further insight on this hypothesis.

## LAKE ERIE

### Phytoplankton

Species lists (Table A13) and summary tables of abundance (Table A14) and biovolume (Table A15) are in Volume 2 - Data Report. A summary of water chemistry parameters is presented in Table 6.

#### Annual Abundance of Major Algal Groups

The phytoplankton assemblage of 1984 was comprised of 356 species representing 104 genera (Table 37). Compared to 1983, a 4.3% reduction in the number of species and a 1.0% increase in the number of genera were observed. Seventy-five percent of the decrease in species number from 1983 to 1984 was due to a decrease in species of Chlorophyta. The total number of species in 1983 (372) and 1984 (356) was considerably higher than the 125 to 150 species observed in all basins in 1970 (Munawar and Munawar 1976).

In 1984 the diatoms possessed the greatest number of species (171, 48% of the total species) and biomass (47.8% of the total) (Tables 37 and 38), while the second largest number of species (96) was observed for the Chlorophyta (Table 37). A similar observation occurred in 1983 (Makarewicz 1987). These diversity observations represent significant changes from 1970, when the Chlorophyta possessed the largest number of species (78) and only 21 diatom species were observed (16.3% of the species) (Table 38). However, diatoms in 1970 still accounted for 53% of the biomass (Munawar and Munawar 1976).

Highest relative densities were attained by the picoplankton (89.6%) in 1984. In 1983 the Chlorophyta had the second highest biomass, while in 1984 they were fourth, slightly lower than the Pyrrhophyta and Cryptophyta.

### Seasonal Abundance and Distribution of Major Algal Groups

The average density and biomass for the sampling period were 45,080 cells/mL (40,055 cells/mL; 1983) and  $1.00 \text{ g/m}^3$  ( $1.36 \text{ g/m}^3$ ; 1984). Seasonally, abundance (cells/mL) peaked in mid-April at 88,762 cells/mL (mean abundance station), decreased through May and July, and leveled off during August. A fall/early winter secondary maximum at ~40,000 cells/mL was observed before a decline to 28,200 cells/mL in February of 1985 (Fig. 45a).

A different pattern emerged from the seasonal biovolume totals. Similar to the seasonal abundance pattern, peak biomass occurred in April. However, biovolume was low in July and steadily increased into September (Fig. 45b) followed by a decrease from December into January and February. Except for the lower biomass in 1983 and 1984, the timing of the spring and autumn biomass peaks is similar to that observed in 1970 (Munawar and Munawar 1976).

Diatoms were the dominant group throughout the year (47.8% of the total biovolume). However, seasonally their importance varied considerably (Fig. 46) but in a pattern similar to 1983 (Makarewicz 1987). Diatoms were dominant in April and May (~60% of the biovolume) and were succeeded by the Cryptophyta in July and the Chlorophyta in August. A similar succession and relative importance were observed in 1983 (Makarewicz 1987) and in 1970 (Munawar and Munawar 1976). By December and through the winter months, the diatoms were again dominant accounting for as much as 78% of the biovolume.

### Geographical Abundance and Distribution of Major Algal Groups

Abundance for the sampling period varied geographically but was similar to 1983 observations (Makarewicz 1987). Biomass generally

decreased eastward. The western basin (Stations 60, 57 and 55) possessed a greater biomass ( $1.38 \text{ g/m}^3$ , S.E.=.23) than the eastern basin ( $0.54 \text{ g/m}^3$ , S.E.=.82) (Stations 18, 15 and 9) and the central basin ( $0.76 \text{ g/m}^3$ , S.E.=.09) (Stations 42, 73, 37, 78 and 79) (Table 39). The considerably greater abundance of the western basin was attributed to the picoplankton (Fig. 47). However, the higher biomass of the western basin (Table 39) was due to greater abundance and biomass of the Bacillariophyta, Cyanophyta, Chlorophyta, Cryptophyta and Chlorophyta in the western basin. The increase in the total abundance, but not in biomass (Table 39), east of Station 78 was attributed to the higher abundance of picoplankton (Fig. 47). Picoplankton contributed little to community biomass (~1.5%, Table 40) because of their extremely small size (0.5 to 2.0  $\mu\text{m}$ ).

As in 1983, the general pattern of higher abundance in the western basin was observed on each sampling date except for perhaps the late fall and early winter cruise (Fig. 48). It appeared that with cooling of the lake in the autumn, abundance became similar throughout the lake (Fig. 48). In 1983 (Makarewicz 1987), at least 12 common species had higher abundances in the western basin. Similarly in 1984, many of the same species had geographical abundance patterns with maxima in the western or central basin (Table 41) (Figs. 48 and 49). A difference in species abundance from the various basins of Lake Erie has been documented previously (Munawar and Munawar 1976, Davis 1969a).

### Picoplankton

Picoplankton abundance in 1984 (mean = 38,075 cells/mL; maximum of  $3.8 \times 10^5$  cells/mL) was not dissimilar from 1983 (mean = 33,171 cells/mL; maximum of  $1.4 \times 10^5$  cells/mL). On a numerical basis, the picoplankton represented 88.2% of the total cells and 6.1% of the total biomass.

Picoplankton relative numerical dominance in 1984 was similar to 1983 (84.5% of total cells). Prior to the 1983 study (Makarewicz 1987), other researchers have not routinely reported on this group of organisms.

#### Regional and Seasonal Trends in the Abundance of Common Species

Common species (Table 40) were arbitrarily defined as those possessing a relative abundance of  $>0.1\%$  of the total cells or  $>0.5\%$  of the total biovolume. Eighty-four percent of the common species observed in 1984 were also common species in 1983. Thirty percent of the common species observed in 1983 were not common in 1984 (Table 41).

The causes of these differences is difficult to evaluate. Natural annual variability of plankton populations in the lake has never been evaluated and can not be evaluated until a longer data set exists. Considerable seasonal sampling variability exists between 1983 and 1984 and is the most probable cause for the species differences observed. For example, Coelastrum microporum was common in 1983 because of its high density in October (Makarewicz 1987). October, September and November samples were not taken in 1984-85.

Because of the similarity of the 1984 common species list to the 1983 list, a species by species description of autecology and regional and seasonal trends are not warranted here and can be referred to in Makarewicz (1987). Only new common species are discussed below.

#### Bacillariophyta

##### Asterionella formosa Hass.

A common species in Lake Michigan and Lake Huron in 1983 and 1984 (Makarewicz 1987, This report), A. formosa was a dominant species in Lake Erie prior to 1950 (Verduin 1964). Hohn (1969) stated that A. formosa



maintained constant densities between 1938 and 1965 but its relative importance declined. Between 1967-1975, a decline in A. formosa was evident from nearshore data (Nichols et al. 1977b). Munawar and Munawar (1976), working with samples from the entire lake, observed that those species, such as A. formosa, dominant before 1950 continued to be less important in 1970. During February of 1976, A. formosa comprised 10.3% of the total biomass but contributed less than 5% of the total biomass on all sampling dates in the western basin (Gladish and Munawar 1980).

In 1975-76, A. formosa was a common species in the central basin in early April (Reuter 1979). However, it was not a common species in 1983. Average abundance and biomass in 1983 were only 8.7 cells/mL and 2.6 mg/m<sup>3</sup>, respectively. It was a dominant species in 1984 (Table 40).

Average abundance and biomass in 1984 were 73.4 cells/mL and 48 mg/m<sup>3</sup>, respectively. Maximum abundance was 942 cells/mL at Station 42 on 1 May 1984. Seasonally, abundance was high in April and peaked by early May (mean station abundance = 278 cells/mL). However, abundance was low the rest of the year (Fig. 51a).

#### Melosira islandica O. Mull.

Historically, M. islandica has not been a common species in Lake Erie. Michalski (1968) noted it as sub-dominant during the vernal and autumnal period from nearshore data in 1966-67. Similarly, Nichols et al. (1977b) believed it to be a spring species between 1967 and 1975. In 1970 M. islandica represented 27.5% of the total biomass on the 21-26 October cruise of Lake Erie (Munawar and Munawar 1976). Gladish and Munawar (1980) did not report this species as common in the western basin in 1975-76; M. granulata was common in 1975-76. Similarly in 1983, M.

granulata was common (Makarewicz 1987) while M. islandica was not (mean abundance = 2.9 cells/mL; mean biomass = 3.0 mg/m<sup>3</sup>).

In 1984 this mesotrophic indicator species (Tarapchak and Stoermer 1976) was the fourth most common diatom on a biomass basis (Table 40). Average abundance was 31.5 cells/mL with a maximum of 1,564 cells/mL at Station 55 on 20 April 1984. Abundance peaked in April (mean station abundance = 190 cells/mL) and was low the rest of the year (Fig. 51b). Geographically, abundance was definitely higher in the western basin (Fig. 49). The high abundance of M. islandica in the western basin of Lake Erie is correlated with the spring bloom of this species in southern Lake Huron.

#### Chlorophyta

##### Crucigenia rectangularis (Brawn) Gay

This species is usually a minor element of summer phytoplankton assemblages of mesotrophic to eutrophic lakes (Stoermer and Ladewski 1976). Historically, this species has not been common in Lake Erie. Abundance in 1983 (mean = 1.9 cells/mL) and 1984 (mean = 5.1 cells/mL) was low. Because of its relatively large size, it became a common species accounting for 1.01% of the total biomass (Table 40). Seasonally, abundance peaked in August (mean station abundance = 41.7 cells/mL) (Fig. 51d).

#### Cyanophyta

##### Anabaena sp.

Starting in 1958, Anabaena became more prevalent during the fall and summer at least through 1963 (Davis 1969a). In 1966-67, short-lived summer pulses of Anabaena were observed at a nearshore station by

Michalski (1968). Munawar and Munawar (1976) observed populations of Anabaena spiroides to be "well developed" in both the western and central basins during the summer of 1970. During 1975-76, Cyanophyta biomass never exceeded 20 mg/m<sup>3</sup>. Aphanizomenon flos-aquae was the most common taxa encountered in 1975-76, while Anabaena sp. occurred less commonly in the central basin (Reuter 1979). Although species are not mentioned, a decrease in Cyanophyta biomass was observed at a nearshore site between 1967 and 1975 (Nichols et al. 1977b). Abundance in 1983 was low (mean abundance = 15.1 cells/mL) (Makarewicz 1987).

In 1984 mean abundance was 47.8 cells/mL. The percent of total biomass (0.87%) for Anabaena sp. was the same as Aphanizomenon flos-aquae during the 1984 study (Table 40). Seasonally, abundance peaked at 255 cells/mL (mean station abundance) on 7 August 1984 (Fig. 51c). A maximum abundance of 867 cells/mL was observed at Station 55 on 19 August 1984. No obvious geographical pattern was observed.

#### Changes in Species Composition

Davis (1969a) has reviewed the extensive earlier work on Lake Erie, while Munawar and Munawar (1982), Gladish and Munawar (1980) and Nicholls (1981) discuss the more recent material. Verduin (1964) has concluded that before 1950 the phytoplankton of western Lake Erie had been dominated by Asterionella formosa, Tabellaria fenestrata and Melosira ambigua, whereas in 1960-61 the dominant forms had been Fragilaria capucina, Coscinodiscus radiatus (probably Actinocyclus normanii f. subsalsus) and Melosira binderana (= Stephanodiscus binderanus).

As with Munawar and Munawar (1976), the 1983 study (Makarewicz 1987) confirmed Verduin's (1964) observations that those species dominant before 1950 (A. formosa, I. fenestrata and M. ambigua) continued to be less

important in the 1983 collections. Actinocyclus normanii f. subsalsa (= Coscinodiscus rothii) and Stephanodiscus binderanus were dominant in 1961-62 (Verduin 1964) and in 1970 (Munawar and Munawar 1976). Fragilaria capucina was a dominant in 1961 but not in 1970. By 1983 Actinocyclus normanii f. subsalsa was only the fifth most prevalent diatom, but on a numerical basis Fragilaria capucina was the second most prevalent diatom in the western basin and in the entire lake (Makarewicz, 1987). In 1984 Actinocyclus normanii f. subsalsa was not even a common species (Table 40).

Dominant species in 1983 and 1984 were Stephanodiscus niagarae, Fragilaria crotonensis, Cosmarium sp., Cryptomonas erosa, Rhodomonas minuta var. nannoplanktica, Oscillatoria subbrevis, Oscillatoria tenuis and Ceratium hirundinella (Table 40). Fragilaria capucina, Coelastrum microporum, Oscillatoria subbrevis and O. tenuis were dominant in 1983 only (Makarewicz 1987), while Anabaena sp., Aphanizomenon flos-aquae and Asterionella formosa were also dominant in 1984.

Asterionella formosa has not been prevalent in Lake Erie since prior to 1950. Verduin (1964) stated that before 1950 Asterionella formosa was a dominant species in western Lake Erie. Similarly, Davis (1969a) reported Asterionella as the dominant organism in the spring pulse of the central basin prior to 1949. Numerous workers (Hohn 1969, Nichols et al. 1977b, Munawar and Munawar 1976, Gladish and Munawar 1980) reported a decline in A. formosa after 1950. The low abundance of A. formosa was apparent into 1983 (mean = 8.7 cells/mL, Makarewicz 1987).

Average density of A. formosa was 73.4 cells/mL in 1984 representing 5.6% of the biomass (Table 40). Maximum density in March of 1938 was 96.6 cells/mL with a March mean of 553 cells/mL (Hohn 1969). No samples were

taken in March of 1984, but the April average was 226 cells/mL (maximum abundance = 942 cells/mL in May ). In 1984 during the three cruises in April and May, Asterionella formosa was the dominant spring species on a biomass basis and the second most important diatom on a numerical basis (Table 43).

Although occurrences of common and dominant species in 1970, 1983 and 1984 were similar, dramatic decreases in abundance of these species were evident (Table 44). This pattern was evident in all three basins.

### Indicator Species

Munawar and Munawar (1982) concluded that the species of phytoplankton found in 1970 usually occurred in mesotrophic and eutrophic conditions. Common species in 1983 included eutrophic indicators (Fragilaria capucina, Melosira granulata, Peridinium aciculiferum, Pediastrum simplex, Scenedesmus ecornis) and mesotrophic indicators (Stephanodiscus niagarae, Fragilaria crotonensis, Tabellaria flocculosa) (Makarewicz 1987). A similar set of major common species occurred in 1984, including the mesotrophic indicators Stephanodiscus niagarae, Fragilaria crotonensis and Tabellaria flocculosa and the eutrophic indicators Fragilaria capucina, Peridinium aciculiferum and Pediastrum simplex. The eutrophic indicators Melosira granulata and Scenedesmus ecornis, common in 1983, were present in 1984 but were not common (>0.1% of the total cells or >0.5% of the total biovolume). Interestingly, a mesotrophic indicator, Melosira islandica, not common in 1983, was common in 1984 accounting for 4.1% of the total biomass (Table 40). However, the abundance of M. islandica in western Lake Erie appears to be influenced by the Lake Huron M. islandica population.

Evidence of a shift in trophic status since 1970 is provided by a comparison of distribution of dominant diatom indicator species in 1970, 1983 and 1984 (Table 45). The number of dominant eutrophic species has decreased, while the number of dominant mesotrophic species has increased. The mesotrophic-eutrophic ratio suggests a shift to mesotrophic conditions for the western basin.

#### Historical Changes in Community Biomass

Between 1927 and 1964, a large and consistent increase in the total abundance of phytoplankton of the central basin had occurred (Davis 1964, 1969a). Nichols et al. (1977b) observed that a decline in nearshore phytoplankton of the western basin occurred between 1967 and 1975. However, Gladish and Munawar (1980) discounted this finding and suggested that no realistic conclusion could be drawn from a comparison of biomass between 1970 and 1975.

The mean basin weighted biomass was 3.4, 1.49 and 0.8 g/m<sup>3</sup> in 1970, 1983 and 1984, respectively. A 56 to 76% reduction in algal biomass has occurred in offshore waters of Lake Erie from 1970 to 1983/84. This reduction in biomass is evident for all seasons of the year (Fig. 52). The historically highly productive western basin (Munawar and Burns 1976) has had a steady decrease in biomass from 1958 to 1984 (Fig. 53). Since 1975 chlorophyll concentrations have decreased in all basins (Fig. 54). Phosphorus levels have also decreased in all sub-basins (Fig. 55). Between 1970 and 1983-1984, dramatic reductions in maximum biomass of common species have occurred (Table 44). For example, in the nuisance species Aphanizomenon flos-aquae, a 96% reduction in the maximum biomass observed has occurred since 1970. Stephanodiscus binderanus, a eutrophic indicator species, has decreased in biomass by 90% in the western basin.

Similary, Fragilaria capucina, another eutrophic indicator, has decreased (99% reduction) dramatically within the phytoplankton community.

Based on maximum biomass concentrations (Vollenweider 1968), Munawar and Munawar (1976) classified the western basin as highly eutrophic, the eastern basin as mesotrophic and the central basin between the mesotrophic and eutrophic conditions. Using the same classification system of Vollenweider (1968):

Ultraoligotrophic	$<1 \text{ g/m}^3$
Mesotrophic	$3 \text{ to } 5 \text{ g/m}^3$
Highly eutrophic	$>10 \text{ g/m}^3$

the western basin (maximum biomass =  $6.6 \text{ g/m}^3$ , Station 55, April) in 1984 would be between mesotrophic and eutrophic, the central basin (maximum biomass =  $3.0 \text{ g/m}^3$ , Station 37, August) would be mesotrophic and the eastern basin (maximum biomass =  $2.0 \text{ g/m}^3$ , Station 15, April) would be between oligotrophic and mesotrophic. Similarly, the classification scheme of Munawar and Munawar (1982), based on mean phytoplankton biomass, suggests an improvement in water quality between 1970 and 1983/84 (Table 46) in all basins of Lake Erie.

## LAKE ERIE

### Zooplankton

#### Annual Abundance of Zooplankton Groups

Species lists (Table A16) and summary tables of abundance (Table A17) and biomass (Table A18) are in Volume 2 - Data Report. The zooplankton assemblage of 1984 comprised 81 species representing 39 genera from the Amphipoda, Calanoida, Cladocera, Cyclopoida, Harpacticoida and the Rotifera. Compared to 1983 (37 genera, 66 species), an 18.5% increase in number of species was observed. This difference was mostly attributable to an increase in number of rotifers (34 to 48).

The Rotifera possessed the largest number of species (48) and relative abundance (80.1%) followed by the Cyclopoida and Calanoida. The nauplius stage of the Copepoda accounted for 10.4% of the total zooplankton abundance (Table 47). On a biomass basis, the importance of the Rotifera dropped to 13.6% of the zooplankton biomass because of their small size, while the Cladocera contributed 40.5% of the biomass (Table 47). Average density and biomass for the study period were  $159,615 \pm 34,000$  organisms /m<sup>3</sup> (mean  $\pm$  S.E.) (288,100/m<sup>3</sup> - 1983) and  $53.6 \pm 6.2$  mg/m<sup>3</sup> (Table 6).

#### Seasonal Abundance and Distribution of Major Zooplankton Groups

Seasonally, biomass distribution (Fig. 56a) was unimodal, peaking in August. The seasonal abundance pattern suggested two peaks: one in spring and a second in late summer (Fig. 56b), which were caused by peaks in rotifer abundance. A sampling pattern that includes the June-July and September-October period is needed to fully evaluate the seasonal distribution patterns.



The 1984 seasonal abundance pattern (Fig. 57) of the various zooplankton groups was similar to 1983 (Makarewicz 1987). Rotifera abundance peaked in May and a secondary peak was noted in late August (Fig. 57). Cladocera and Calanoida abundance was low in spring, peaked in early August and decreased the rest of the year. Cyclopoida achieved their highest abundance in late August (Fig. 57a). The biomass seasonal distribution pattern of the major zooplankton groups generally mimicked the abundance pattern (Fig. 58).

#### Geographical Abundance and Distribution of Zooplankton Groups

Geographically, zooplankton abundance was similar to 1983 (Makarewicz 1987), with abundance being higher in the western basin and decreasing easterly to Station 79 (Fig. 59). Abundance increased slightly eastward through the eastern basin (Stations 18, 15 and 9). The Rotifera were the cause of the high zooplankton abundance in the western basin, although the Copepoda nauplii also had a slightly higher abundance in the western basin (Stations 60, 57, 55) (Fig. 59b).

Interestingly, biomass was similar in all three basins of Lake Erie (Fig. 60a) even though Rotifera biomass was highest in the western basin, particularly at the most western Station 60. The high rotifer biomass was countered by a low Cladocera biomass at Station 60 (Fig. 60b), while at the next easterly station (57), Rotifera biomass was low and Cladocera biomass was high. A low Cladocera abundance was observed at Station 60 in 1983 (Makarewicz 1987). Perhaps there is an influence of the Detroit River at this station that affects Cladocera abundance negatively and Rotifera positively.

Except for Station 60, Cladocera abundance generally decreased eastward into and through the central basin. In the eastern basin,

Cladocera biomass (Fig. 60b), but not abundance (Fig. 59b), increased easterly. Cyclopoida and Calanoida abundance was higher in the central and eastern basin as compared to the western basin.

#### Common Species

Common Crustacea species (Table 48) were arbitrarily defined as those possessing a relative abundance  $>0.1\%$  of the total abundance or  $1.0\%$  of the total biomass. Rotifera species were considered common if they accounted for  $>1.0\%$  of the total zooplankton abundance or biomass. The number of common species in 1983 (25) and 1984 (27) was similar, but there were changes in composition of the common species. Daphnia pulicaria, common in 1984, was not observed in 1983 in Lake Erie. Leptodora kindtii, Keratella earlinae and Notholca squamula, common in 1984, were present in 1983 but not common. Common species observed in 1983, but not in 1984, included Diaptomus siciloides, Diaphanosoma leuchtenbergianum, Colletheca sp. and Kellicottia longispina.

#### Changes in Species Composition

##### Crustacea

Brooks (1969) suggested that a shift in the Lake Erie cladoceran assemblage was evident by 1948-49 with smaller cladocerans, such as Daphnia galeata mendotae, D. retrocurva and Diaphanosoma sp., being more abundant than in 1938-39. In 1970 the most commonly found Daphnia species were D. retrocurva, D. galeata mendotae and D. longiremis (Watson and Carpenter 1974); Bosmina longirostris and Eubosmina coregoni were more abundant (Watson and Carpenter 1974). Predominant cladoceran species in 1983 were small forms similar to those observed in 1970. In 1983 the predominant Cladocera in descending order were Eubosmina coregoni, Daphnia galeata mendotae, Bosmina longirostris, Diaphanosoma leuchtenbergianum and

Chydorus sphaericus (Makarewicz 1987). In 1984, on a numerical basis, the predominant Cladocera were Daphnia galaeta mendotae, Eubosmina coregoni, Bosmina longirostris, Daphnia pulicaria, Daphnia retrocurva and Chydorus sphaericus (Table 48). Between 1983 and 1984, essentially the same common species, with the exception of D. pulicaria, were present with minimal change in rank abundance. These changes in rank order may be attributed to the difference in the seasonal sampling pattern between 1983 and 1984.

On a biomass basis, Daphnia pulicaria was the dominant Cladocera for the lake, with a major bloom in August. It was most prominent in the central and eastern basins (Fig. 61a). A reexamination of the August 1983 samples revealed that D. pulicaria was present. Apparently the taxonomist included this species under Daphnia spp. in the 1983 counts (N. Andresen, Personal Communication). The existence of the large D. pulicaria is a major finding. This species was first observed in Lake Michigan in 1978 (Evans 1985) and was a dominant species in 1983 in Lake Michigan and the third most important cladoceran in Lake Huron in 1983 (Makarewicz 1987). The occurrence of this species in large numbers in Lake Erie may be an important factor, along with decreasing phosphorus loading, in explaining the decreasing phytoplankton abundance observed in Lake Erie (This study). Large populations of Daphnia pulicaria have been correlated with low algal biomass (Osgood 1983, Vanni 1983).

A rare species in the offshore waters of the western basin in 1929-30 (Tidd 1955), Chydorus sphaericus was a prominent constituent in the 1950's (Davis 1962) and in 1970 with a higher abundance in the western basin (Watson and Carpenter 1974). In 1983 and 1984, this species contributed 0.2% and 0.1%, respectively, of the total abundance (Makarewicz 1987).

(Table 48). Chydorus sphaericus has established itself as a common species in Lake Erie.

The prevalence of Cyclops vernalis has changed over the past 50 years. In the 1930's, C. vernalis was found only in the extreme western end of Lake Erie at the mouth of the Detroit and Maumee Rivers (Tidd 1955). By 1967 it had spread throughout the lake (Davis 1969b). Patalas (1972) and Watson (1976) reported it as numerous in the western basin of Lake Erie during the late 60's and 70's. This species was not observed in 1983 (Makarewicz 1987), while in 1984 it was not common (Table 48) but did average 25.9 organisms/m<sup>3</sup> for the entire lake. However, it was more prevalent in the western basin (83/m<sup>3</sup>) as compared to the eastern and central basins (3.3/m<sup>3</sup>).

The dominant cyclopoid copepod in 1970 was Cyclops bicuspidatus thomasi with Mesocyclops edax common in the summer (Watson and Carpenter 1974). Cap (1980) documented a shift in predominant copepods in the eastern basin from calanoids in 1928 to cyclopoid copepods, mainly Cyclops bicuspidatus thomasi, in 1974. Tropocyclops prasinus was present in low numbers (Watson and Carpenter 1974). In 1983 and 1984, the same three species (C. bicuspidatus thomasi, M. edax and T. prasinus) predominated (Makarewicz 1987) (Table 48).

Abundance of Diaptomus siciloides has increased in Lake Erie (Gannon 1981). It was most prevalent in the western basin and western portion of the central basin in the late 60's and 70's (Patalas 1972, Watson 1976). Abundant diaptomids in the eastern and central basins in 1970 were Diaptomus oregonensis and D. siciloides, which were also the predominant calanoids in Lake Erie in 1983 and 1984 (Makarewicz 1987) (Table 48). D.

sicilloides was not a common species (1.0% of total zooplankton) in 1984 but was the second most abundant calanoid.

#### Rotifera

Davis' studies (1968, 1969a) of the zooplankton of Lake Erie included rotifers. Certain soft-bodied rotifers were not identified nor were the samples quantitative for rotifers as a number 20 net was employed. However, it is apparently the only lake-wide study of the offshore that included the rotifers.

Species observed to be abundant in 1967 were Brachionus angularis, B. calyciflorus, Conochilus unicornis, Keratella cochlearis, K. quadrata, Kellicottia longispina, Synchaeta stylata and Polyarthra vulgaris (Davis 1968, 1969a). In 1983 a similar group of abundant rotifers was found (Makarewicz 1987). In decreasing order of relative abundance (% of total abundance), the abundant species in 1983 were: Polyarthra vulgaris (18.4%), Synchaeta sp. (9.5%), Keratella cochlearis (7.3%), Conochilus unicornis (5.3%), Keratella hiemalis (3.5%), Brachionus sp. (3.0%) (Makarewicz 1987). Polyarthra vulgaris (22.49%) and Synchaeta sp. (9.46%) were still dominant in 1984 along with Notholca squamula (11.06%), which was not a common species in 1983. Other abundant rotifers in 1984 included Polyarthra major (4.94%), Keratella cochlearis (4.91%) and Notholca laurentiae (3.21%) (Table 48). Except for the addition of the species of Notholca in 1984, the 1983 and 1984 rotifer composition was similar to 1967. Although it was only the fourteenth most abundant rotifer, Kellicottia longispina was still prevalent in 1983, but not 1984, representing 1.3% of the total abundance (Makarewicz 1987). Only Keratella quadrata was apparently not as prominent in 1983 and 1984 as it was in 1967.

### East-West Species Distribution

Numerous researchers (e.g. Davis 1969b, Watson 1974, Patalas 1972, Gannon 1981) have documented the differences in species composition and abundance from the central, western and eastern basins of Lake Erie. As in 1983 (Makarewicz 1987), a number of species, all rotifers in 1984, had higher abundances in the western basin (Figs. 59a&b). Geographically, Cyclops bicuspidatus thomasi, Mesocyclops edax and Diaptomus oregonensis had geographical abundance patterns with maxima in the central basin in 1983 (Makarewicz 1987) and 1984 (Fig. 61a). Holopedium gibberum (1983) and Tropocyclops prasinus mexicanus (1983 and 1984) were more prevalent in the eastern basin (Fig. 61b).

### Indicators of Trophic Status

Zooplankton have potential value as assessors of trophic status (Gannon and Stemberger 1978). Rotifers, in particular, respond more quickly to environmental changes than do the crustacean plankton and appear to be sensitive indicators of changes in water quality (Gannon and Stemberger 1978). Brachionus angularis, B. calyciflorus, Filinia longiseta and Trichocerca multicornis are four rotifer species indicative of eutrophy. Also, species in the genus Brachionus are particularly good indicators of eutrophy in the Great Lakes (Gannon 1981). Of the three dominant rotifer species in Lake Erie, P. vulgaris is a eurytopic species; Notholca squamula is a cold stenotherm often associated with oligo-mesotrophic lakes (Gannon and Stemberger 1978) during the summer that is also often encountered in eutrophic lakes during the winter or early spring (as in Lake Erie in 1984); and some species of Synchaeta are eutrophic indicators (Gannon and Stemberger 1978). The lack of dominance of eutrophic indicator species for the entire lake suggests that Lake Erie

In 1984, as a unit, is not eutrophic. This would agree well with the conclusion from the phytoplankton indicator species and from the algal biomass classification of trophic status of Lake Erie..

However, the eutrophic indicators Brachionus caudatus, B. calyciflorus, B. angularis, Filinia longiseta, Trichocerca multicornis and Trichocerca cylindrica had abundances restricted to or significantly higher in the western basin (Table 49). Total zooplankton abundance was also higher in the western basin. As with phytoplankton biomass and species composition, both rotifer abundance and species composition indicated a greater degree of eutrophy in the western basin than in the central or eastern basins.

Another measure of trophic status is the calanoid/cyclopoid plus cladoceran ratio (plankton ratio) (Gannon and Stemberger 1978, McNaught et al. 1980a, Krieger 1981). Calanoid copepods generally appear best adapted for oligotrophic conditions, while cladocerans and cyclopoid copepods are relatively more abundant in eutrophic waters (Gannon and Stemberger 1978). In Lake Erie, this ratio increased from west to east in 1983 and 1984 (Table 50) indicating a more productive status for the western basin as compared to the rest of the lake.

The higher algal biomass (Table 39) of the western basin as compared to the central and eastern basins was reflected in the higher abundance of zooplankton, eutrophic zooplankton species composition and the low plankton ratio. Compared to Lakes Huron and Michigan in 1983 and 1984, abundance of zooplankton was greatest and the plankton ratio was lower in Lake Erie (Table 6), indicating the higher trophic status of Lake Erie compared to Lakes Huron and Michigan.

### Historical Changes in Abundances

Zooplankton data exists for the western basin of Lake Erie from 1939 to 1984. The 1939 (Chandler 1940; 49 collections), 1949 (Bradshaw 1964; 30 collections) and 1959 (Hubschmann 1960; daily collections July and August) collections were taken with a 10-liter Juday trap equipped with a 64-um mesh net in the western basin. A 1970 study by Nalepa (1972) is not included in the analysis because it is from the far western end of the basin and may not be representative of the entire western basin. The 1961 study of Britt et al. (1973) sampled twice monthly from mid-June to mid-September, while Davis (1968) used a 76-um mesh net in July of 1967. Because of the comparable net sizes, all these studies, with the exception of Nalepa's (1972), are comparable to the 1983 (Makarewicz 1987) and 1984 surveys.

A comparison of the April-December Crustacea means of 1939, 1949, 1983 and 1984 suggests an increase in zooplankton abundance from 1939 to 1949 (Fig. 63). Similarly, the mean abundance for July and August from 1939 to 1961 suggests a similar increase in zooplankton (Fig. 64). Both Bradshaw (1964) and Gannon (1981) concluded similarly. Average ice-free abundances from 1949 to 1983 suggest a decreasing but insignificant downward trend (Fig. 63). A major decrease in zooplankton abundance is suggested from 1983 to 1984 (Fig. 63). It is difficult to evaluate this drop in biomass because of the large gap in data from 1950 to 1983. It could simply be annual natural variability. However, the Huron and Michigan zooplankton abundance did not display such a great variability from 1983 to 1984. Focusing on July and August, where more data are available, an abundance decrease in Cladocera, Copepoda and total Crustacea from the 1961 maximum (Fig. 64) is evident.



A data point in the early 70's would be of interest. Data do exist for the 70's. However, Nalepa's (1972) study is from the far western portion of the western basin. Watson and Carpenter (1974) sampled the western basin, as well as the central and eastern basins in 1970. Their data is reported as a weighted lake average and is not available to compare with other years in the western basin. As the sampling method (1970; vertical hauls, 64-um mesh) is comparable to those used in 1983 and 1984, these data are also directly comparable on a lake-wide basis. A seasonal comparison of weighted lake-wide means suggests little change in zooplankton abundance from 1970 and 1983 during the spring and autumn. However, 1984 values are generally lower than 1983 and 1970 data points (Fig. 65). The importance of a sampling point between mid-May through July in 1983 and 1984, the generally recognized period of peak abundance, is apparent from this figure.

The 1939 and 1961 rotifer samples were collected with a 64-um mesh net, as in the 1983 and 1984 works. An increase in Rotifera abundance in the western basin is suggested since 1939 (Fig. 66).

### Trophic Interactions

Long-term changes of phytoplankton and zooplankton abundance were apparent. A 56 to 76% reduction in lake-wide offshore algal biomass has occurred from 1970 to 1983 to 1984. Total phosphorus and chlorophyll *a* levels in each basin decreased (Figs. 53 and 54). Similarly, where comparable data are available, zooplankton abundance and biomass decreased in the western basin, while a decrease in lakewide zooplankton biomass during the summer period from 1970 to 1984 is suggested. With the N/P ratio currently exceeding 30 to 1, apparently due to P-control, nuisance blue-green algae species, such as Aphanizomenon flos-aqua, decreased.

These changes are consistent with expectations of long-term nutrient control .

There are, however, significant changes in the composition of the zooplankton community that can not be attributed solely to nutrient control. The appearance of the large cladoceran Daphnia pulicaria in Lake Erie was evident in 1983 and 1984. Its dominance with a major bloom in August of 1984 was surprising for it suggested changes in planktivory in Lake Erie (Wells 1970, Brooks and Dodson 1965, Carpenter et al. 1985, Scavia et al. 1986).

A recovery in the walleye fishery of Lake Erie is evident by the increasing harvest and abundance (Fig. 67). Annual walleye harvest rapidly increased from 112,000 fish in 1975 to 2.2 million fish in 1977 in the Ohio Lake Erie waters (western and central basins) (Ohio Department of Natural Resources 1985). Annual harvests since 1978 have stayed high but ranged from 1.7 million to the record 4.1 million in 1984 (Ohio Department of Natural Resources 1985). Central basin harvests have increased dramatically over the past two years (Fig. 68). The initial recovery of the walleye fishery is attributed to the closing of the walleye fishery in 1970 due to mercury contamination and to the exclusion of commercial fishing for walleyes in U.S. waters since 1972 (Kutkahn et al. 1976).

In addition, salmonid stocking programs exist in New York, Pennsylvania, Ohio and Ontario. New York, which has the largest stocking program, has a target stocking of ~1 million fish in 1987 (F. Cornelius, Personal Communication). Lake trout, Chinook and Coho salmon and various strains of rainbow/steelhead trout are stocked in New York waters. These fish are primarily feeding on smelt (NYSDEC 1987).

Seasonal diets of walleye closely followed changes in forage-fish availability (Knight et al. 1984). Between 1979 and 1981 in the western basin of Lake Erie, walleye ate (100% by volume) age-1 shiners Notropis atherinoides (emerald shiner) and N. hudsonius (spottail shiner) in spring but switched to age-0 clupeids (60-90%) Dorosoma cepedianum (gizzard shad) and Alosa pseudoharengus (alewife) in late July. Clupeids and shiners composed 25-70% and 10-40%, respectively, of the diets of age-1 or older walleyes in autumn (Knight et al. 1984). There does appear to be a difference in walleye foraging from west to east. Recent stomach analyses of walleye from New York and Pennsylvania waters indicate that smelt represent 90% of their diet (NYSDEC 1987 and R. Kenyon, Personal Communication,). Smelt are not abundant in the western and central basins.

Dramatic changes have occurred in the forage species of Erie. It is apparent that alewife, spottail shiner and emerald shiner have declined in the western and central basins (Fig. 69) and in Pennsylvania waters (R. Kenyon, Personal Communication). The decline of spottail and emerald shiners between 1982-1984 is impressive in view of the massive increase in walleye harvest in the central basin since 1982 (Fig. 68). Fishery biologists have no specific reason for this decline. Besides predation, other possible causes of the decline include climatic factors, turbidity changes, toxic chemicals and the commercial bait industry. Whatever the cause, a decrease in planktivorous shiners has occurred.

Emerald and spottail shiners feed heavily on microcrustacean, some midge larvae and algae (Scott and Crossman 1973, Smith and Kramer 1964, McCann 1959). Evidence gathered by Gray (1942) in Lake Erie during December indicated that Diaptomus, Daphnia, Cyclops and Bosmina were all

important in the diet of the emerald shiner but at different times of the day. Dymond (1926) noted that in the spottail shiner of Lake Nipigon, Daphnia formed 40% of the diet although Bosmina, Sida and Leptodora were also eaten. A study on current shiner diets would be useful to the ongoing discussion on trophic interaction in Lake Erie.

There is good evidence that planktivorous fish abundance has changed as a result of the walleye resurgence but perhaps also from the salmonid stocking program in Lake Erie. Release from planktivore pressure could have led to the establishment of the large Daphnia pulicaria in Lake Erie. Other top-down effects are difficult to evaluate. For instance, a clearer water column, as observed in Lake Michigan and attributed to cascading effects (Scavia et al. 1986), is difficult to evaluate in Lake Erie. For example, the decrease in Aphanizomenon flos-aquae in Lake Erie is more readily attributed to decreased phosphorus concentration and the increasing N/P ratio (Smith 1983) than the influence of large zooplankton such as Daphnia pulicaria on the phytoplankton assemblage (Lynch 1980, Bergquist et al 1985). However, the reappearance and dominance of Asterionella formosa in 1984 may be related to the presence of D. pulicaria (e.g. Bergquist et al. 1985). In an ecosystem dominated by large and more efficient herbivores, such as Daphnia pulicaria, a grazing effect on phytoplankton would be expected.

The index of dispersion (Elliot 1971) indicates a highly contagious distribution of phytoplankton and zooplankton in Lake Erie. Could the patchy distribution of phytoplankton be related to zooplankton herbivory on phytoplankton; that is, was there top down control (i.e. grazing) on phytoplankton on a short-term basis? Table 51 lists correlation coefficients of phytoplankton abundance versus total phosphorus and

zooplankton abundance for each cruise on Lake Erie. For each cruise, 11 stations were sampled covering the entire length of the lake over a short period of time. Interpretation of the correlations were as follows: A negative correlation between a zooplankton group and phytoplankton implied grazing pressure on phytoplankton, while a positive correlation between total phosphorus and phytoplankton abundance would suggest an enhancement of phytoplankton abundance due to phosphorus.

All correlations were positive in April, suggesting that phosphorus was influencing the food web. A different situation was evident by May. Phytoplankton were blooming (Fig. 45) and all zooplankton groups increased in abundance (Fig. 56). High negative correlations existed for zooplankton suggesting a top-down influence on phytoplankton abundance. Interestingly, a negative correlation existed for TP versus phytoplankton implying that phosphorus was not the major factor controlling phytoplankton abundance on this spring date. As expected, when D. pulicaria became dominant in August, a negative fairly high correlation existed between D. pulicaria and phytoplankton. During this same period, Daphnia spp., in general, and Rotifera were not negatively correlated spatially with changes in phytoplankton abundance. By December, other species of Daphnia and Calanoida exerted some influence on phytoplankton abundance.

Calanoids were negatively correlated with phytoplankton abundance throughout the year, except in April, suggesting a constant baseline effect on phytoplankton abundance. In a lake such as Erie, where a large efficient Daphnia sp. is added to the food web, the new species induces grazing pressures previously not present during the summer. Thus during the summer, a greater grazing pressure leads to a decrease in algae, an

Increase in transparency and a decrease in turbidity. A decrease in turbidity during the August bloom of D. pulicaria was observed in Lake Erie in 1984 (Fig. 70). Turbidity levels in the central and western basins have decreased since 1978 (Table 52). Similarly, a large increase in transparency was attributed to grazing of D. pulicaria in Lake Michigan (Scavia et al. 1986).

Except for the May bloom, total phosphorus positively correlated well with phytoplankton abundance spatially on Lake Erie. At least two factors were controlling the phytoplankton abundance. Because of the higher correlation, it is tempting to suggest that phosphorus was the primary control on phytoplankton abundance. This was not true during the spring phytoplankton bloom where zooplankton obviously affected the bloom. Although P-control was evident during the summer, there were also fairly high negative correlations between phytoplankton and Daphnia pulicaria and calanoids. This exercise suggests that "top down" and "bottom up" control of the trophic web of lake ecosystems exists simultaneously and that it varies with season.

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TABLE 1. Plankton sampling dates for Lakes Michigan, Huron and Erie in 1984 and 1985. Only phytoplankton samples were taken during the winter helicopter cruises of 1985.

Cruise	Lake Michigan	Lake Huron	Lake Erie
1984			
1	4/9-12	4/12-15	4/18-19
2	5/6-7	5/4-5	4/20-21
3	-	-	5/1-2
4	7/8-9	7/5-7	7/2-3
5	8/1-3	8/3-4	8/5-6
6	8/12-14	8/10-12	8/7-9
7	8/15-16	8/17-18	8/19-20
8	11/27-29	11/30-12/2	12/4-5
9	12/13-18	12/10-12	12/5-8
1985			
10	-	1/15-16	1/14-14
11	2/7-9	2/9-10	2/17-18

TABLE 2. Latitude and longitude of plankton sampling stations, 1984.

Station Number	Latitude	Longitude
LAKE ERIE		
LE60	41°53'30"	83°11'48"
LE57	41 49 54	83 01 06
LE55	41 44 18	82 44 00
LE42	41 57 54	82 02 30
LE73	41 58 40	81 45 25
LE37	42 06 36	81 34 30
LE78	42 07 00	81 15 00
LE79	42 15 00	80 48 00
LE18	42 25 18	80 04 48
LE15	42 31 00	79 53 36
LE09	42 32 18	79 37 00
LAKE HURON		
LH93	44 06 00	82 07 00
LH92	43 48 30	82 22 00
LH91	43 42 00	82 01 00
LH90	43 24 00	82 18 00
LH61	45 45 00	83 55 00
LH57	45 40 00	83 43 36
LH54	45 31 00	83 25 00
LH53	45 27 00	82 54 54
LH48	45 16 42	82 27 06
LH45	45 08 12	82 59 00
LH43	45 00 48	82 00 30
LH38	44 44 24	82 03 36
LH37	44 45 42	82 47 00
LH34	44 38 24	83 13 54
LH32	44 27 12	82 20 30
LH29	44 22 00	81 50 00
LH27	44 11 54	82 30 12
LH15	44 00 00	82 21 00
LH12	43 53 24	82 03 24
LH09	43 38 00	82 13 00
LH06	43 28 00	82 00 00

Table 2 (continued).

## LAKE MICHIGAN

LM05	42 00 00	87 25 00
LM06	42 00 00	87 00 00
LM10	42 23 00	87 25 00
LM11	42 23 00	87 00 00
LM17	42 44 00	87 25 00
LM18	42 44 00	87 00 00
LM22	43 08 00	87 25 00
LM23	43 08 00	87 00 00
LM26	43 36 00	87 22 00
LM27	43 36 00	86 55 00
LM32	44 08 24	87 14 00
LM34	44 05 24	86 46 00
LM40	44 45 36	86 58 00
LM41	44 44 12	86 43 18
LM46	45 13 24	86 36 48
LM47	45 10 42	86 22 30
LM56	45 37 30	86 18 00
LM57	45 38 12	86 03 30
LM64	45 57 00	85 35 12
LM77	45 47 24	84 49 24



Table 4. Sample dates and stations for Lake Huron, 1984 and 1985.

Station Number	4/ 12-15	5/ 4-5	7/ 5-7	8/ 3-4	8/ 10-12	8/ 17-18	11/ 27-2	12/ 10-13	1/ 15-16	2/ 9-10
6	x		x	x		x	x			
90		x			x			x	x	x
9	x		x	x		x	x		x	x
91		x			x					
12	x		x	x		x	x			
92		x			x			x		
15	x		x	x		x	x		x	x
27	x		x	x		x	x			
93		x			x			x		
29		x			x			x		
32	x		x	x		x	x			
34									x	x
37	x		x	x		x	x		x	x
38		x			x			x		
43		x			x			x		
45	x		x	x		x	x		x	x
48		x			x			x		
53		x			x			x		
54	x		x	x		x	x			x
57		x			x			x		x
61	x		x	x		x	x			x

TABLE 5. Comparison of calculated crustacean dry weights (ug) to measured dry weights in Lake Michigan. Measured weights from Hawkins and Evans (1979).

Species	Calculated				Measured	
	mean weight	mean length	range	(n)	mean weight	range
<i>Cyclops bicuspidatus thomasi</i>	4.2	.97	3.0-5.3	63	3.2 1.9	1.9-5.6 1.2-2.9
<i>Cyclops vernalis</i>	8.6	.97	5.9-12.2	8	5.6 2.5	4.8-6.4 2.4-2.6
<i>Diaptomus ashlandi</i>	2.6	.96	2.2-3.2	65	4.8 3.9	2.1-7.1 1.9-5.6
<i>Diaptomus minutus</i>	2.4	.93	1.9-2.9	63	3.2 2.8	1.7-4.9 1.8-4.4
<i>Diaptomus oregonensis</i>	5.1	1.26	3.2-6.7	45	6.9 5.6	3.8-10.9 3.3-10.1
<i>Diaptomus sicilis</i>	7.1	1.44	5.3-10.2	61	17.3 11.4	13.4-23.6 8.6-11.4
<i>Limnocalanus macrurus</i>	29.3	2.57	20.5-35.0	59	45.3 33.8	13.2-88.2 16.7-55.8
<i>Tropocyclops prasinus mexicanus</i>	1.3	.59	0.9-1.8	59	.9	0.7-1.2
Cyclopoid copepodite	.7	.54	0.2-1.4	65	1.2	0.6-2.2
<i>Bosmina longirostris</i>	1.4	.39	0.6-3.2	39	1.0	0.6-1.8
<i>Chydorus sphaericus</i>	1.9	.34	1.7-2.1	4	1.0	0.8-1.2
<i>Daphnia galeata mendotae</i>	10.0	1.32	2.6-20.1	42	4.0	2.5-8.9
<i>Daphnia retrocurva</i>	5.2	1.04	1.6-11.2	26	2.9	1.2-6.5
<i>Eubosmina coregoni</i>	2.5	.49	0.9-6.1	36	1.7	1.2-2.5
<i>Holopedium gibberum</i>	12.0	.95	6.3-20.2	13	5.0	1.9-10.9
<i>Polyphemus pediculus</i>	13.6	.87	4.3-36.9	6	2.9	2.2-4.1
<i>Epischura lacustris</i>	9.4	1.61	5.4-13.0	22	10.8	5.9-13.9
<i>Eurytemera affinis</i>	4.9	1.25	-	1	4.8	3.9-5.3

Table 6. Mean values ( $\pm$ S.E.) of physical-chemical parameters (April-October) from a 1-m depth for Lakes Erie, Michigan and Huron, 1984. Values are in mg/L unless noted otherwise. Values in parentheses represent number of samples analyzed. Phytoplankton samples are from April to February. Zooplankton samples are from April to November. The trophic ratio and zooplankton ratio are discussed in the text.

	Erie	Michigan	Huron
pH	8.25 $\pm$ .03(101)	8.23 $\pm$ .03(83)	8.02 $\pm$ .03(101)
Alkalinity	92.5 $\pm$ .43(106)	106.9 $\pm$ .56(85)	77.4 $\pm$ .31(106)
Conductivity (umhos/cm)	272.4 $\pm$ 1.54(106)	273 $\pm$ 1.38(85)	202.9 $\pm$ .83(106)
Turbidity (NTU)	4.5 $\pm$ .85(88)	.39 $\pm$ .03(75)	0.32 $\pm$ .02(88)
Soluble Reactive Silica (mg/L)	178.9 $\pm$ 21.7(106)	360.1 $\pm$ 22(85)	644.6 $\pm$ 19.9(106)
Chloride	14.61 $\pm$ .25(105)	8.79 $\pm$ .08(85)	5.66 $\pm$ .05(105)
Sulfate	22.70 $\pm$ .20(105)	21.22 $\pm$ .14(84)	16.09 $\pm$ .11(105)
Nitrite + Nitrate	0.29 $\pm$ .02(106)	0.22 $\pm$ .006(85)	0.30 $\pm$ .004(106)
Total phosphorus (ug/L)	16.55 $\pm$ 1.41(105)	4.63 $\pm$ .24(84)	3.70 $\pm$ .25(105)
Soluble Reactive Phosphorus (ug/L)	2.0 $\pm$ .33(100)	0.92 $\pm$ .10(71)	0.80 $\pm$ .10(100)
Sodium	7.18 $\pm$ .16(32)	4.75 $\pm$ .03(30)	3.17 $\pm$ .05(32)
Potassium	1.40 $\pm$ .02(32)	1.30 $\pm$ .01(30)	0.94 $\pm$ .01(32)
Chl a	3.45 $\pm$ .31(105)	0.86 $\pm$ .05(84)	0.64 $\pm$ .04(105)
Phytoplankton (1000x $\frac{\#}{\text{mL}}$ )	45.1 $\pm$ 4.2 (117)	22.2 $\pm$ 1.4(97)	17.2 $\pm$ .89(95)
(g/m <sup>3</sup> )	1.0 $\pm$ .08(117)	0.55 $\pm$ .038(97)	0.38 $\pm$ .10(95)
Zooplankton (1000x $\frac{\#}{\text{m}^3}$ )	159.6 $\pm$ 25.3(65)	59.8 $\pm$ 8.3(65)	55.4 $\pm$ 7.2(49)
(mg/m <sup>3</sup> )	53.6 $\pm$ 6.2(65)	33.2 $\pm$ 4.9(65)	27.3 $\pm$ 2.3(49)
Trophic ratio	1.8	4	3.8*
Zooplankton ratio	0.35	0.64	1.50

\* Average of 1983 and 1984



TABLE 7. Number of species and genera observed in each algal division or grouping in Lake Michigan, 1983 and 1984. Results are for the non-winter period.

Division	Species		Genera	
	1983	1984	1983	1984
Bacillariophyta	168	166	33	29
Chlorophyta	86	63	36	26
Chrysophyta	49	33	13	11
Cryptophyta	23	20	4	4
Cyanophyta	21	13	10	8
Picoplankton	(2) <sup>1</sup>	3	(2) <sup>1</sup>	3
Colorless flagellates	16	15	6	5
Pyrrhophyta	9	7	4	3
Euglenophyta	1	1	1	1
Unidentified	5	5	-	-
Chloromanophyta	1	0	1	0
	<hr/>	<hr/>	<hr/>	<hr/>
Total	379	327	108	91

<sup>1</sup> Included in Cyanophyta in 1983

TABLE 8. Relative abundance of major phytoplankton divisions in Lake Michigan, 1983 and 1984. Bac=Bacillariophyta, Cat=Chloromonophyta, Chl=Chlorophyta, Chr=Chrysophyta, Col=Colorless flagellates, Cry=Cryptophyta, Cya=Cyanophyta, Pic=Picoplankton, Eug=Euglenophyta, Pyr=Pyrrhophyta, Uni=Unidentified.

Division	% Biovolume/mL		% Cells/mL	
	1983	1984	1983	1984
Bac	56.41	69.97	1.07	2.04
Cat	0.02	0.00	0.01	0.00
Chl	5.25	1.99	0.65	0.67
Chr	6.53	5.01	1.49	2.18
Col	0.75	0.41	0.13	0.30
Cry	13.43	11.61	1.24	1.50
Cya	5.56*	1.65	92.21	3.54
Pic	-	1.39	-	82.85
Eug	0.04	0.07	0.01	<0.01
Pyr	7.32	2.36	0.01	0.02
Uni	4.68	5.53	3.20	6.89

\*Picoplankton are included with the Cyanophyta in 1983.

Table 9. Abundance of Rhizosolenia eriensis in Lake Michigan in 1983 and 1984. Values in parentheses represent R. eriensis+R. longiseta.

1983			1984		
Date	cells/mL	% biovolume	Date	cells/mL	% biovolume
4/17	0.0	0.0	4/9	10.3	17.5(30.5)
4/26	0.0	0.0	5/6	9.3	8.6(17.4)
5/4	0.2	0.1	7/8	52.4	33.4(36.1)
7/4	0.0	0.0	8/1	22.6	23.2(25.0)
8/3	0.0	0.0(.05)	8/12	17.5	26.9(30.1)
8/17	0.0	0.0	8/15	21.9	39.2(44.6)
10/12	10.9	9.1(9.2)	11/27	3.2	7.9 (8.3)
10/26	7.1	2.1(10.7)	12/13	8.3	16.4(17.0)
			2/7	4.8	4.6 (5.2)

TABLE 10. Summary of common phytoplankton species occurrence in Lake Michigan during 1984 and winter of 1985. Summary is based on all samples analyzed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of  $>0.1\%$  of the total cells or  $>0.5\%$  of the total biovolume.

Taxon	Maximum Cells/mL	Average Cells/mL	% of Total Cells	Mean Biovolume $\mu\text{m}^3/\text{mL}$	% of Total Biovolume
<b>BACILLARIOPHYTA</b>					
Asterionella formosa	184	22.4	0.10	6,130	1.12
Cyclotella comensis v. 1	2,568	115.6	0.52	3,539	0.65
Cyclotella comta	96	4.4	0.02	11,561	2.12
Cyclotella ocellata	265	23.3	0.10	2,079	0.38
Fragilaria capucina	161	11.9	0.05	3,940	0.72
Fragilaria crotonensis	376	74.3	0.33	48,175	8.83
Melosira islandica	96	12.6	0.06	13,538	2.48
Melosira italica subsp. subarctica	74	10.8	0.05	2,784	0.51
Nitzschia lauenburgiana	10	0.7	0.00	4,506	0.83
Rhizosolenia eriensis	110	18.2	0.08	129,063	23.64
Rhizosolenia longiseta	162	21.2	0.10	23,928	4.38
Stephanodiscus alpinus	18	2.2	0.01	8,318	1.52
Stephanodiscus alpinus?	11	0.7	0.00	4,267	0.78
Stephanodiscus niagarae	14	1.1	0.01	17,571	3.22
Stephanodiscus transilvanicus	7	0.8	0.00	16,294	2.99
Synedra filiformis	118	11.2	0.05	4,225	0.77
Synedra ulna v. chaseana	23	2.2	0.01	17,151	3.14
Tabellaria flocculosa	82	13.9	0.06	41,459	7.60
<b>CHLOROPHYTA</b>					
Monoraphidium contortum	344	36.8	0.17	385	0.07
Oocystis submarina	254	25.8	0.12	417	0.08
Dictyosphaerium ehrenbergianum	278	23.6	0.11	196	0.03
<b>CHRYSDOPHYTA</b>					
Chrysophyceae coccoids	630	83.1	0.37	320	0.06
Dinobryon divergens	303	26.5	0.12	5,443	1.00
Dinobryon sociale v. americanum	1,743	111.7	0.50	11,052	2.02
Haptophyte sp.	1,456	182.3	0.82	1,633	0.30
<b>COLORLESS FLAGELLATES</b>					
Colorless flagellates	311	26.5	0.12	424	0.08
Monosiga ovata	352	24.5	0.11	310	0.06
<b>CRYPTOPHYTA</b>					
Chroomonas norstedtii	270	48.8	0.22	1,480	0.27
Cryptomonas erosa	65	11.2	0.05	25,171	4.61
Cryptomonas marsonii	25	3.7	0.02	4,948	0.91
Cryptomonas rostratiformis	25	1.3	0.01	4,572	0.84
Rhodomonas minuta v. nannoplanktica	965	232.5	1.05	17,683	3.24
<b>CYANOPHYTA</b>					
Anacystis montana v. minor	2,790	292.6	1.32	1,276	0.23
Coelosphaerium naegelianum	982	31.9	0.14	153	0.03
Oscillatoria limnetica	2,070	209.8	0.94	1,023	0.19
Oscillatoria minima	4,132	175.5	0.79	3,737	0.68
<b>PICOPLANKTON</b>					
rods	4,287	886.6	3.99	2,415	0.44
spheres	43,541	16,716.3	75.23	4,481	0.82
spherical - flagellates	2,847	805.6	3.63	714	0.13
<b>PYRRHOPHYTA</b>					
Gymnodinium sp.	16	0.5	0.00	4,111	0.75
Peridinium sp.	16	1.5	0.01	4,275	0.78
<b>UNIDENTIFIED</b>					
Unidentified flagellate - ovoid	4,287	1,0026.3	4.62	23,103	4.23
Unidentified flagellate - spherical	1,350	503.2	2.26	6,771	1.24

TABLE 11. Common species observed in either 1983 or 1984, but not both years, Lake Michigan. Common species were arbitrarily defined as having an abundance of >0.1% of the total cells or >0.5% of the total biovolume.

<u>1983</u>	<u>1984/1985</u>
<b>Bacillariophyta</b>	
Cyclotella michiganiana	Cyclotella ocellata
Cymatopleura solea	Rhizosolenia longiseta
Entomoneis ornata	Nitzschia lauenburgiana
Fragilaria vaucheriae	Synedra filiformis
Tabellaria fenestrata	Synedra ulna v. chaseana
<b>Chlorophyta</b>	
Cosmarium sp.	Oocystis submarina
Stichococcus sp.	Dictyosphaerium ehrenbergianum
<b>Chrysophyta</b>	
Dinobryon cylindricum	-
Stylothea aurea	-
<b>Cryptophyta</b>	
Cryptomonas erosa v. reflexa	Cryptomonas rostratiformis
Cryptomonas pyrenoidifera	
<b>Cyanophyta</b>	
Gomphosphaeria naegelianum	Oscillatoria minima
Oscillatoria agardhii	
<b>Pyrrhophyta</b>	
Ceratium hirundinella	

Table 12. Number of species in Lake Michigan with depth at Station 47, 15 August 1986.

Depth (m)	Division					
	Bac	Chl	Chr	Cry	Cya	Pic
1	13	1	9	5	1	3
5	11	3	9	4	2	3
10	30	4	7	5	2	3
15	23	5	7	3	3	3
20	27	10	8	6	5	3

TABLE 13. Comparison of abundance of Cyclotella species at offshore sites in August of 1970, 1983 and 1984, Lake Michigan. Data from Holland and Beeton (1972), Makarewicz (1987) and this study. Stations 22 and 27 are geographically comparable to Holland and Beeton's offshore sites. Values are in cells/mL.

	11 August 70 (offshore stations)	17 August 83 (Stations 22&27)	15 August 84 (Stations 22&27)
<i>Cyclotella</i> <i>michiganiana</i>	71 - 182	0.44 - 6.8	0.38 - 4.5
<i>Cyclotella</i> <i>stelligera</i>	300 - 613	0.17 - 2.2	1.7 - 2.8

TABLE 14. Comparison of nutrient levels between Stations 6, 64, 77 and all other stations during the spring and fall, Lake Michigan. Mean $\pm$ S.E.

	Silica (ug/L)	Total Phosphorus (ug/L)	Nitrate + Nitrite (mg/L)
	=====	=====	=====
Station 77	632.7 $\pm$ 23.2	4.67 $\pm$ 1.08	.27 $\pm$ .01
Station 64	364.5 $\pm$ 22.8	6.35 $\pm$ 2.16	.20 $\pm$ .01
Lake Mean (excluding Station 77)	501.0 $\pm$ 14.4	5.14 $\pm$ .35	.26 $\pm$ .01
Station 6	502.8 $\pm$ 38.9	4.05 $\pm$ .41	.27 $\pm$ .01



TABLE 15. Distribution of indicator diatom species in Lake Michigan. The classification scheme followed Tarapchak and Stoermer (1976).  $M_1$ =mesotrophic but intolerant of nutrient enrichment,  $M_2$ =mesotrophic and tolerant of moderate nutrient enrichment, E=eutrophic. <sup>2</sup>1970-71, 1977 and 1983 data are from Holland and Beeton (1972), Stoermer and Tuchman (1979) and Makarewicz (1987).

	$M_1$	$M_2$	E	$M_1+M_2/E$
1977 <sup>2</sup> (Nearshore)	6	5	7	1.6
1970-71 <sup>3</sup>	5	3	1	8.0
1983 <sup>1</sup>	6	2	2	4.0
1984 <sup>1</sup>	5	3	2	4.0

<sup>1</sup> Only diatoms contributing >.5% of the biomass for a cruise are classified.

<sup>2</sup> Only diatoms contributing >1% (1977) or >0.1% (1984) of the abundance are classified.

<sup>3</sup> Only "predominant" species are classified.

Table 16. Relative abundance of zooplankton in Lake Michigan.

	<u>Percent Biomass</u>		<u>Percent Abundance</u>	
	1983	1984	1983	1984
Rotifera	N	2.6	59.7	67.5
Cladocera	O C			
	T A	39.8	3.2	4.1
Copepoda nauplii	L			
	C	11.2	21.3	15.6
Cyclopoida	U			
	L	15.8	5.7	6.2
Calanoida	A			
	T	30.4	10.1	6.6
Mysidacea	E			
	D	0.2	<.1	<.01
Harpacticoida		<.1	<.1	<.01

TABLE 17. Summary of common zooplankton species occurrence in Lake Michigan during 1984. Values are from the short zooplankton hauls only. Species were arbitrarily classified as common if they accounted for >0.1% of the total abundance or 1.0% of the total biomass, with the exception of rotifers. Rotifer species were considered common if they accounted for >1.0% of the total abundance.

Taxon	Maximum Density #/m <sup>3</sup>	Average Density #/m <sup>3</sup>	% of Total Density	Mean Biomass ug/m <sup>3</sup>	% of Total Biomass
=====					
COPEPODA					
Copepoda - nauplii	62127	9183	15.60	3673	11.23
Cyclopoida					
Cyclopoid - copepodite	14358	2767	4.70	1797	5.50
Cyclops bicuspidatus thomasi	5475	749	1.27	3057	9.35
Tropocyclops prasinus mexicanus	439	60	.10	73	.22
Calanoida					
Diaptomus - copepodite	30508	2518	4.28	3676	11.24
Diaptomus ashlandi	5098	848	1.44	2162	6.61
Diaptomus minutus	695	132	.22	321	.98
Diaptomus sicilis	1062	2157	.37	1478	4.52
Limnocalanus macrurus	469	56	.09	1637	5.01
		TOTAL	22.07		54.67
CLADOCERA					
Bosmina longirostris	29566	942	1.60	876	2.68
Daphnia galeata mendotae	9110	846	1.44	6825	20.88
Daphnia pulicaria	690	78	.13	1638	5.01
Daphnia retrocurva	5286	238	.40	1389	4.25
Eubosmina coregoni	1465	125	.21	271	.83
Holopedium gibberum	4333	136	.23	1132	3.46
Leptodora kindtii	255	27	.05	779	2.38
		TOTAL	4.06		39.49
ROTIFERA					
Collotheca sp.	6814	1134	1.93	8	.02
Conochilus unicornis	8850	942	1.60	17	.05
Gastropus stylifer	18843	1241	2.11	18	.05
Kellicottia longispina	43489	5649	9.60	49	.15
Keratella cochlearis	124128	11764	19.99	65	.20
Notholca foliacea	21396	798	1.36	20	.06
Notholca laurentiae	52609	2325	3.95	77	.24
Notholca squamula	50381	2200	3.74	37	.11
Polyarthra remata	20550	1105	1.88	30	.09
Polyarthra vulgaris	47790	5785	9.83	82	.25
Synchaeta sp.	27545	4223	7.18	98	.30
		TOTAL	63.15		1.53
			=====		=====
			95.29		95.69

TABLE 18. Cladoceran abundance in 1954, 1966, 1968, 1983 and 1984 in Lake Michigan. Data from Wells (1970), Makarewicz (1987) and this study. Values are in number /m<sup>3</sup>

Species and Year	Early August
<i>Leptodora kindtii</i>	
1954	29
1966	4
1968	16
1983	34
1984	98
<i>Daphnia galeata</i>	
1954	1200
1966	0
1968	0.4
1983	514
1984	3508
<i>Daphnia retrocurva</i>	
1954	1400
1966	79
1968	2100
1983	82
1984	1061
<i>Diaphanosoma brachyurum</i>	
1954	2
1966	0
1968	0
1983	1
1984	0
<i>Daphnia longiremis</i>	
1954	0
1966	16
1968	0
1983	0
1984	14
<i>Daphnia pulicaria</i>	
1954	0
1966	0
1968	0
1983	1011
1984	248
<i>Holopedium gibberum</i>	
1954	0
1966	2
1968	5
1983	456
1984	536
<i>Polyphemus pediculus</i>	
1954	2
1966	15
1968	10

TABLE 18. (continued)

1983	13
1984	7
<i>Bosmina longirostris</i>	
1954	26
1966	98
1968	16
1983	342
1984	5231(141)*
<i>Eubosmina coregoni</i>	
1954	0
1966	1
1968	16
1983	159
1984	208
<i>Ceriodaphnia quadrangula</i>	
1954	0
1966	4
1968	1
1983	0
1984	0

\* Bloom at Station 77 and 64. Mean for the offshore waters minus Station 77 and 64 is in parentheses.

TABLE 19. Copepod abundance in 1954, 1966, 1968, 1983 and 1984 in Lake Michigan. Data from Wells (1970), Makarewicz (1987) and this study. Values are number/m<sup>3</sup>.

Species and Year	Early August
<i>Limnocalanus macrurus</i>	
1954	91
1966	34
1968	270
1983	18
1984	64
<i>Epischura lacustris</i>	
1954	41
1966	7
1968	21
1983	19
1984	14
<i>Diaptomus sicilis</i>	
1954	3
1966	1
1968	3
1983	79
1984	155
<i>Mesocyclops edax</i>	
1954	200
1966	0
1968	0
1983	13
1984	31
<i>Senecella calanoides</i>	
1954	0.2
1966	0.2
1968	0.1
1983	1.4
1984	0
<i>Cyclops bicuspidatus</i>	
1954	310
1966	1000
1968	860
1983	1457
1984	2807
<i>Diaptomus ashlandi</i>	
1954	140
1966	220
1968	13
1983	1256
1984	1733
<i>Cyclops vernalis</i>	
1954	0
1966	0
1968	0
1983	0

TABLE 19. (continued).

1984	16
<i>Eurytemora affinis</i>	
1954	0
1966	33
1968	3
1983	0
1984	0
<i>Diaptomus oregonensis</i>	
1954	63
1966	58
1968	100
1983	138
1984	58
<i>Diaptomus minutus</i>	
1954	39
1966	25
1968	1500
1983	151
1984	183

Table 20. Average crustacean zooplankton biomass (dry weight) for 1976 and 1984, Lake Michigan. The 1976 data (Bartone and Schelske 1982) were converted to dry weight assuming carbon content was 50% of dry weight.

1976	$50.0 \pm 14.8 \text{ mg/m}^3$
1984	$33.6 \pm 14.7 \text{ mg/m}^3$



TABLE 21. The ratio of calanoids to cyclopoids plus cladocerans geographically in Lake Michigan, 1983 and 1984.

Station	<u>Calanoida</u>	
	Cyclopoida + Cladocera	
	<u>1983</u>	<u>1984</u>
77 (North)	0.37	0.23
64	0.41	0.20
57	1.74	0.69
47	1.52	0.57
41	1.10	0.57
34	1.03	0.80
27	1.53	0.84
23	1.15	1.32
18	3.01	1.93
11	1.71	1.09
6 (South)	0.87	0.75

Table 22. Correlation of phytoplankton with total phosphorus concentrations and zooplankton abundance within individual cruises ( 11 stations) in Lake Michigan, 1984. NO = not observed.

	Daphnia pulex	Daphnia spp.	Rotifera	Calanoida	Total Phosphorus
4/9-12	NO	.794	.395	-.707	-.385
5/6-7	-.132	-.327	.715	-.738	-.113
8/1-3	-.021	.137	.768	-.059	.330
8/15-16	-.272	-.496	-.031	.243	.191
11/27-29	-.171	-.016	.680	.455	-.156
12/18	-.095	.594	.763	-.164	.653

TABLE 23. Number of species and genera observed in each algal division or grouping, Lake Huron, 1983 and 1984.

Division	<u>Species</u>		<u>Genera</u>	
	1983	1984	1983	1984
BAC	158	156	29	28
CHL	73	64	28	28
CHR	36	35	10	12
CRY	22	17	3	4
CYA	13	13	6	7
PIC	(2)*	3	(2)*	3
COL	13	13	4	5
PYR	10	9	4	4
EUG	4	1	3	1
UNI	3	4	-	-
CAT	1	0	1	0
	<hr/>	<hr/>	<hr/>	<hr/>
Total	329	315	88	92

\* Included in Cyanophyta in 1983

TABLE 24. Relative abundance of major phytoplankton divisions in Lake Huron, 1983 and 1984. In 1983 picoplankton are included with the Cyanophyta. BAC=Bacillariophyta, CAT=Chloromonophyta, CHL=Chlorophyta, CHR=Chrysophyta, COL=Colorless Flagellates, CRY=Cryptophyta, CYA=Cyanophyta, PIC=Picoplankton, EUG=Euglenophyta, PYR=Pyrrhophyta, UNI=Unidentified.

Division	<u>% Biovolume/mL</u>		<u>% Cells/mL</u>	
	1983	1984	1983	1984
BAC	68.20	61.90	1.16	2.78
CAT	.02	0.00	.01	0.00
CHL	3.45	2.72	.42	.58
CHR	7.11	9.45	1.60	2.08
COL	.14	.19	.06	.14
CRY	8.29	9.10	1.13	1.24
CYA	4.31*	1.41	89.53*	4.15
PIC	-	1.60	-	83.85
EUG	.11	.06	.01	.01
PYR	3.25	7.15	.01	.02
UNI	5.11	6.41	6.09	5.14

\* Picoplankton included in Cyanophyta in 1983.

Table 25. Abundance of Rhizosolenia eriensis in Lake Huron, 1983 and 1984. Values in parentheses in 1983 represent Rhizosolenia sp. and in 1984 R. longiseta.

1983			1984		
Date	cells/mL	% biovolume	Date	cells/mL	% biovolume
4/21	0.1	0.01	4/12	6.3	9.0(0.43)
5/6	0.2	0.01(38.3)	5/4	5.4	6.3(0.46)
7/2	0.0	0.0 (59.2)	7/5	51.0	18.1(0.81)
8/4	0.0	0.0 (11.3)	8/3	26.7	30.4(0.92)
8/19	0.0	0.0 (12.8)	8/10	33.1	35.1(0.15)
			8/17	9.9	29.1(0.51)
10/16	0.4	1.0 (6.1)	11/27	5.8	16.1(0.39)
10/24	0.0	0.0 (8.7)	12/10	2.9	10.3(0.44)
			1/15	2.4	4.4(0.0)
			2/9	10.7	12.4(0.17)

TABLE 26. Summary of common phytoplankton species occurrence in Lake Huron during 1984 and winter of 1985. Summary is based on all samples analyzed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of >0.1% of the total cells or >0.5% of the total biovolume.

Taxon	Maximum cells/mL	Average cells/mL	% of Total Cells	Mean Biovolume um <sup>3</sup> /mL	% of Total Biovolume
<b>BACILLARIOPHYTA</b>					
<i>Asterionella formosa</i>	168	27.5	.16	9,225	2.13
<i>Cyclotella comensis</i>	1386	122.2	.71	5,781	1.49
<i>Cyclotella comta</i>	35	2.3	.01	8,178	1.89
<i>Cyclotella kuetzingiana</i> v. <i>planetophora</i> ?	135	13.2	.08	3,902	.90
<i>Cyclotella ocellata</i>	1000	113.2	.66	9,784	2.26
<i>Cyclotella stelligera</i>	267	25.3	.15	614	.14
<i>Fragilaria crotonensis</i>	375	44.7	.26	39,333	9.09
<i>Fragilaria intermedia</i> v. <i>fallax</i>	25	2.6	.02	2,233	.52
<i>Melosira islandica</i>	43	6.5	.04	8,752	2.02
<i>Rhizosolenia eriensis</i>	131	17.2	.10	81,644	18.87
<i>Rhizosolenia longiseta</i>	33	2.9	.02	2,355	.54
<i>Stephanodiscus alpinus</i>	19	1.5	.01	3,950	.91
<i>Stephanodiscus minutus</i>	85	19.4	.11	851	.20
<i>Stephanodiscus niagarae</i>	2	0.2	.00	3,562	.82
<i>Tabellaria flocculosa</i>	181	25.0	.15	69,337	16.02
<b>CHLOROPHYTA</b>					
<i>Cosmarium</i> sp.	16	.7	.00	2,173	.5
<b>CHRYSOPHYTA</b>					
Chrysophycean coccoids	160	36.2	.21	189	.04
<i>Chrysosphaerella longispina</i>	1325	31.3	.18	8,313	1.92
<i>Dinobryon cylindricum</i>	196	13.3	.08	4,298	.99
<i>Dinobryon divergens</i>	254	32.0	.19	6,544	1.51
<i>Dinobryon sociale</i>	589	65.6	.38	10,771	2.49
<i>Dinobryon sociale</i> v. <i>americanum</i>	540	27.8	.16	4,716	1.09
Haptophyte sp.	589	110.1	.64	1,460	.34
<b>CRYPTOPHYTA</b>					
<i>Chroomonas norstedtii</i>	115	22.8	.13	724	.17
<i>Cryptomonas erosa</i>	31	4.5	.03	10,333	2.39
<i>Cryptomonas pyrenoidifera</i>	33	4.2	.02	2,450	.57
<i>Cryptomonas rostratiformis</i>	8	.8	.00	3,290	.76
<i>Rhodomonas minuta</i> v. <i>nannoplanktica</i>	360	155.1	.90	13,772	3.18
<b>CYANOPHYTA</b>					
<i>Anacystis montana</i> v. <i>minor</i>	4606	445.4	2.59	2,205	.51
<i>Coelosphaerium naegelianum</i>	1047	77.6	.45	335	.08
<i>Gomphosphaeria lacustris</i>	851	79.0	.46	380	.09
<i>Oscillatoria limnetica</i>	942	45.9	.27	219	.05
<i>Oscillatoria minima</i>	335	17.3	.10	453	.10
<b>PICOPLANKTON</b>					
rods	2741	811.6	4.73	2,568	.59
spheres	29690	13021.0	75.84	3,768	.87
spherical - flagellates	2160	563.2	3.28	592	.14
<b>PYRRHOPHYTA</b>					
<i>Ceratium hirundinella</i>	8	.1	.00	14,991	3.46
<i>Gymnodinium helveticum</i> f. <i>achroum</i>	6	.2	.00	3,566	.82
<i>Gymnodinium</i> sp.	8	.5	.00	3,312	.77
<i>Gymnodinium</i> sp. 2	8	.3	.00	5,816	1.34
<b>UNIDENTIFIED</b>					
Unidentified flagellate - ovoid	1481	615.9	3.59	17,740	4.10
Unidentified flagellate - spherical	2193	264.7	1.54	9,767	2.26

TABLE 27. Common species observed in either 1983 or 1984 but not in both years, Lake Huron.

<u>1983</u>	<u>1984/85</u>
<b>Bacillariophyta</b>	
Stephanodiscus transilvanicus	Cyclotella stelligera Stephanodiscus alpinus Stephanodiscus minutus
<b>Chlorophyta</b>	
-	Cosmarium sp.
<b>Cryptophyta</b>	
-	Cryptomonas rostratiformis
<b>Cyanophyta</b>	
Anacystis thermalis Coccochloris elabans	Oscillatoria minima

Table 28. Distribution of indicator diatom species in Lake Huron. The classification scheme of Tarapchak and Stoermer (1976) was utilized.  $M_1$ =mesotrophic but intolerant of nutrient enrichment,  $M_2$ =mesotrophic and tolerant of moderate nutrient enrichment, E=eutrophic. <sup>1</sup>1971, 1975-76 and 1983 data are from Munawar and Munawar (1979), Lin and Schelske (1978) and Makarewicz (1987).

	$M_1$	$M_2$	E	$M_1+M_2/E$
1971 <sup>1</sup>	6	3	3	3.0
1975-76 <sup>2</sup>	2	4	2	3.0
1983 <sup>3</sup>	7	2	2	4.5
1984 <sup>3</sup>	6	3	3	3.0

<sup>1</sup> Only diatoms contributing >5% of the seasonal biomass are classified.

<sup>2</sup> Only "abundant" diatom species are classified.

<sup>3</sup> Only diatoms contributing >0.5% of the biomass for the study period are classified.



Table 29. Relative abundance of zooplankton in Lake Huron.

	<u>Percent Biomass</u>		<u>Percent Abundance</u>	
	1983	1984	1983	1984
Rotifera	N	2.5	41.1	56.0
	O			
Cladocera	T C	27.5	4.8	2.9
	A			
Copepoda nauplii	L	14.7	23.1	18.6
	C			
Cyclopoida	U	13.3	11.2	7.3
	L			
Calanoida	A	42.0	19.8	15.3
	T			
Amphipoda	E	<.1	0.0	<.1
	D			
Mysidacea		0.0	<.1	0.0

TABLE 30. Summary of common zooplankton species occurrence in Lake Huron during 1984. Values are from the short zooplankton hauls only. Species were arbitrarily classified as common if they accounted for >0.1% of the total abundance or 1.0% of the total biomass, with the exception of rotifers. Rotifer species were considered common if they accounted for >1.0% of the total abundance.

Taxon	Maximum Density #/m <sup>3</sup>	Average Density #/m <sup>3</sup>	% of Total Density	Mean Biomass ug/m <sup>3</sup>	% of Total Biomass
=====					
COPEPODA					
Copepoda - nauplii	24749	10071	18.59	4028	14.73
Cyclopoida					
Cyclopoid - copepodite	12791	3254	6.01	1750	6.40
Cyclops bicuspidatus					
thomasi	1487	316	.58	1356	4.96
Mesocyclops					
copepodite	3262	300	.55	205	.75
Mesocyclops edax	270	40	.07	283	1.03
Calanoida					
Diaptomus - copepodite	22584	6174	11.40	5020	18.36
Diaptomus ashlandi	2960	1071	1.98	2189	8.01
Diaptomus minutus	1306	369	.68	720	2.63
Diaptomus oregonensis	256	93	.17	363	1.33
Diaptomus sicilis	2044	502	.93	2377	8.69
Limnocalanus macrurus	266	20	.04	525	1.92
		TOTAL	41.00		68.81
CLADOCERA					
Bosmina longirostris	3304	338	.62	303	1.11
Daphnia galaeta					
mendotae	4127	586	1.08	3136	11.47
Daphnia pulicaria	935	71	.13	1017	3.72
Eubosmina coregoni	3441	326	.60	709	2.59
Holopedium gibberum	2124	158	.29	1658	6.06
Leptodora kindtii	133	16	.03	416	1.52
		TOTAL	2.76		26.48
ROTIFERA					
Collotheca sp.	3584	672	1.24	4	.01
Conochilus unicornis	66009	10878	20.08	239	.87
Gastropus stylifer	9855	1094	2.02	26	.09
Kellicottia longispina	19274	3784	6.99	45	.16
Keratella cochlearis	51995	6652	12.28	24	.09
Notholca squamula	6804	570	1.05	11	.04
Polyarthra remata	5916	650	1.20	17	.06
Polyarthra vulgaris	18086	2917	5.38	117	.43
Synchaeta sp.	12963	1489	2.75	42	.16
		TOTAL	52.99		1.92
			=====		=====
			96.75		97.21

Table 31. Comparison of mean crustacean abundance for the sampling period in 1971 (April-November), 1974/75 (April-November), 1983 (August-October) and 1984 (April-December), Lake Huron. 1971 data modified from Watson and Carpenter (1974), 1974/75 data from McNaught et al. (1980) and 1983 data from Makarewicz (1987). NF = not found. Values are in number/m<sup>3</sup>.

	1971	1974/75**	1983***	1984
<b>Cladocera</b>				
<i>Bosmina longirostris</i>	553 (1047)*	4109	518	338
<i>Eubosmina coregoni</i>	330 (765)*	2084	229	326
<i>Daphnia retrocurva</i>		361	74	36
<i>Daphnia galeata mendotae</i>	339 (852)*	692	1029	586
<i>Daphnia longiremis</i>				
<i>Daphnia pulicaria</i>	0 (0)	0	363	71
<i>Chydorus sphaericus</i>	18	391	NF	NF
<i>Holopedium gibberum</i>	229 (580)*	576	58	158
<b>Cyclopoida</b>				
<i>Cyclops bicuspidatus</i>				
<i>thomasi</i>	3764 (3274)*	1271	2346	316
<i>Cyclops vernalis</i>	7.5 (5)*	117	.5	1.5
<i>Tropocyclops prasinus</i>				
<i>mexicanus</i>	63 (61)*	310	577	21
<i>Mesocyclops edax</i>	5 (6.7)*	91	115	40
<b>Calanoida</b>				
<i>Diaptomus ashlandi</i>	246 (37)*	745	206	1071
<i>Diaptomus minutus</i>	462 (322)*	966	465	369
<i>Diaptomus sicilis</i>	117 (77)*	496	145	502
<i>Diaptomus oregonensis</i>	109 (92)*	192	140	93
<i>Limnocalanus macrurus</i>	64 (44)*	34	9.3	20

\* August, September and October average

\*\* Includes Saginaw Bay

\*\*\* August and October average

Table 32. Abundance of selected zooplankton species in northern and southern Lake Huron in 1984. Values are number/m<sup>3</sup>. Southern Lake Huron is defined as south of Station 27.

	Conochilus unicornis	Kellicottia longispina	Diaptomus minutus	Holopedium gibberum
Northern	12,526	3,897	298	239
Southern	4,729	2,449	383	29

TABLE 33. Ratio of Calanoida to Cladocera plus Cyclopoida in Lake Huron, 1983 and 1984.

Station	<u>Calanoida</u> Cyclopoida + Cladocera		Mean
	1983	1984	
61 (North)	0.67	0.90	0.74
54	1.11	1.36	1.24
45	1.19	1.84	1.52
37	1.57	1.33	1.45
32	2.13	1.46	1.80
27	1.37	1.16	1.27
15	1.60	-	-
12	1.98	1.83	1.91
09	1.31	2.00	1.66
06 (South)	1.23	1.89	1.56

Table 34. Comparison of the plankton ratio (Calanoida/Cyclopoida+Cladocera) between the northern stations of Lake Huron and Lake Michigan.

	1983	1984	mean
Lake Michigan			
Station 77	0.37	0.23	0.32
Lake Huron			
Station 61	0.67	0.90	0.78
Lake Mean	1.49	1.61	1.55

TABLE 35. Mean abundance of rotifers in Lake Huron in 1974 and 1983. Data from Stemberger et al. (1979), Makarewicz (1987) and this study. NF = not found in short tow.

	<u>1974</u>	<u>1980</u>	<u>1983</u>	<u>1984</u>
	April-Nov. #/L	April-July #/L	Aug.-Oct. #/L	April-Dec. #/L
<i>Colletheca</i> sp.	0.8	0.0	0.90	0.67
<i>Conochilus unicornis</i>	15.0	0.79	7.10	10.87
<i>Filinia longiseta</i>	3.4	<.01	0.004	0.007
<i>Gastropus stylifer</i>	5.2	0.27	1.10	1.09
<i>Kellicottia longispina</i>	6.8	1.15	2.10	3.78
<i>Keratella cochlearis</i>	41.9	1.86	2.00	6.65
<i>Keratella earlinae</i>	10.9	<.01	0.08	0.10
<i>Notholca squamula</i>	7.4	1.8	NF	0.57
<i>Polyarthra dolichoptera</i>	3.0	0.12	0.07	0.43
<i>Polyarthra remata</i>	6.8	0.12	0.01	0.65
<i>Polyarthra vulgaris</i>	17.6	0.05	3.00	2.92
<i>Synchaeta kitina</i>	8.1	NF	NF	NF
<i>Synchaeta stylata</i>	7.1	NF	NF	NF
<i>Synchaeta</i> sp.	2.4	1.03	0.10	1.5

Table 36. Correlation (r) of phytoplankton abundance with total phosphorus concentrations and zooplankton abundance within individual cruises (10 stations) in Lake Huron, 1984. NO = observed.

	Daphnia pulex	Daphnia spp.	Rotifera	Calanoida	Total Phosphorus
5/4-5	-.110	-.110	.393	-.370	-.032
8/3-4	-.258	-.698	.595	.010	.144
8/17-18	-.286	-.060	-.662	-.549	-.314
11/30-12/2	-.218	-.460	.420	.101	-.168
12/10-13	.380	.415	.049	-.192	.378



Table 37. Number of species and genera observed in each algal division or grouping, Lake Erie, 1983 and 1984. Bac=Bacillariophyta, Cat=Chloromonophyta, Chl=Chlorophyta, Chr=Chrysophyta, Col=Colorless flagellates, Cry=Cryptophyta, Cya=Cyanophyta, Pic=Picoplankton, Eug=Euglenophyta, Pyr=Pyrrhophyta, Uni=Unidentified.

Division	<u>Species</u>		<u>Genera</u>	
	1983	1984	1983	1984
BAC	176	171	30	30
CHL	108	96	38	38
CHR	29	28	11	14
CRY	14	15	3	4
CYA	16	18	9	10
PIC	-	3*	-	0
COL	15	11	6	4
PYR	8	9	4	4
EUG	2	0	2	0
UNI	3	4	0	0
CAT	1	1	0	0
TOTAL	372	356	103	104

\* Included in Cyanophyta in 1983.

TABLE 38. Number of species identified and percentage of species belonging to various taxonomic groups, Lake Erie. 1970 data represent the mean for the central, western and eastern basins [modified from Munawar and Munawar (1976)].

	1970	1983	1984
<u>Number of Species</u>	<u>134.3</u>	<u>372</u>	<u>356</u>
Division	<u>Percent Composition</u>		
BAC	16.3	47.3	48.0
CHL	58.0	29.0	27.0
CHR	6.3	7.8	7.9
CYA	11.2	4.3	5.1
CRY	3.3	3.8	4.2
EUG	0.7	0.5	0.0
PYR	4.0	2.2	0.0
PIC	-	-	0.8
UNI	-	0.8	1.1
COL	-	4.0	3.1

Table 39. Phytoplankton and zooplankton biomass, total phosphorus and chlorophyll *a* concentrations in the western, central and eastern basins of Lake Erie, 1983 and 1984. Values are in g/m<sup>3</sup> unless noted otherwise.

	Western	Central	Eastern	Entire Lake (mean±S.E.)
Phytoplankton				
1983	1.49	1.59	0.84	1.36±.12
1984	1.38	0.76	0.54	1.00±.16
mean	1.44	1.18	0.69	1.18
Zooplankton				
1984	0.055	0.052	0.054	0.053±.0062
1984 (#/L)	295.6	94.3	130.4	159.6±25
Total Phosphorus				
1983(ug/L)	26.77	16.82	12.79	
1984(ug/L)	23.91	19.37	12.41	
Chlorophyll <i>a</i>				
1983(ug/L)	5.68	4.05	2.22	
1984(ug/L)	5.10	3.27	2.11	

TABLE 40. Summary of common phytoplankton species occurrence in Lake Erie during 1984 and winter of 1985. Summary is based on all samples analyzed. Summary includes the maximum population density encountered, the average population density and biovolume, and the relative abundance (% of total cells and % of total biovolume). Common species were arbitrarily defined as having an abundance of >0.1% of the total cells or >0.5% of the total biovolume.

Taxon	Maximum Cells/mL	Average Cells/mL	% of Total Cells	Mean Biovolume um <sup>3</sup> /mL	% of Total Biovolume
<b>BACILLARIOPHYTA</b>					
Asterionella formosa	942	73.4	0.16	48,802	5.57
Fragilaria capucina	407	38.2	0.08	10,764	1.23
Fragilaria crotonensis	826	77.9	0.17	66,983	7.53
Melosira islandica	1564	31.5	0.07	35,812	4.09
Stephanodiscus alpinus	198	8.7	0.02	17,522	2.00
Stephanodiscus binderanus	2506	59.2	0.13	21,539	2.46
Stephanodiscus niagarae	120	4.9	0.01	135,855	15.51
Stephanodiscus sp.	781	78.3	0.17	6,991	0.80
Tabellaria flocculosa	207	15.8	0.04	33,732	3.85
<b>CHLOROPHYTA</b>					
Cosmarium sp.	25	1.0	0.00	39,142	4.47
Crucigenia rectangularis	295	5.1	0.01	10,087	1.15
Oocystis borgei	180	8.0	0.02	9,357	1.07
Pediastrum simplex v. duodenarium	393	7.8	0.02	10,685	1.22
<b>CHRYSOPHYTA</b>					
Haptophyte sp.	1317	151.9	0.34	2,670	0.30
<b>COLORLESS FLAGELLATES</b>					
Colorless flagellates	2119	65.2	0.14	1,619	0.18
Stelethomonas dichotoma	1186	87.8	0.19	3,500	0.40
<b>CRYPTOPHYTA</b>					
Chroomonas norstedtii	425	50.9	0.11	1,219	0.14
Cryptomonas erosa	295	24.3	0.05	45,760	5.23
Cryptomonas rostratiformis	33	1.6	0.00	5,132	0.59
Rhodomonas minuta v. nannoplanktica	2348	499.1	1.11	39,038	4.46
<b>CYANOPHYTA</b>					
Anabaena sp.	1162	47.8	0.11	7,603	0.87
Anacystis montana v. minor	22253	1052.1	2.33	4,892	0.56
Aphanizomenon flos-aquae	2643	103.6	0.23	7,598	0.87
Coelosphaerium naegelianum	3436	78.1	0.17	333	0.04
Merismopedia tenuissima	6218	85.6	0.19	103	0.01
Oscillatoria limnetica	5179	112.7	0.25	421	0.05
<b>PICOPLANKTON</b>					
rods	10987	1,128.5	2.50	3,154	0.36
spheres	379,888	38,075.3	84.46	10,207	1.17
spherical - flagellates	1726	544.8	1.21	644	0.07
<b>PYRRHOPHYTA</b>					
Ceratium hirundinella	82	2.8	0.01	37,283	4.26
Gymnodinium sp. 2	33	2.2	0.00	31,523	3.60
Peridinium aciculiferum	41	1.3	0.00	12,634	1.44
Peridinium sp.	82	5.5	0.01	25,308	2.89
<b>UNIDENTIFIED</b>					
Unidentified flagellate - ovoid	4303	1177.5	2.61	51,864	5.92
Unidentified flagellate - spherical	2479	558.1	1.24	16,609	1.90

Table 41. Location of maximum abundance of selected species in 1983 and 1984, Lake Erie.

	<u>1983</u>	<u>1984</u>
<i>Fragilaria crotonensis</i>	Western	Western
<i>Fragilaria capucina</i>	Western	Western
<i>Melosira granulata</i>	Western	not common
<i>Melosira islandica</i>	not common	Western
<i>Stephanodiscus</i> sp.	not common	Western
<i>Stephanodiscus binderanus</i>	Western	Western
<i>Tabellaria flocculosa</i>	Western	Western
<i>Oscillatoria tenuis</i>	Western	not common
<i>Oscillatoria limnetica</i>	Western	Western
<i>Oscillatoria subbrevis</i>	Western	not common
<i>Anacystis montana</i> var. minor	not common	Western
<i>Aphanizomenon flos-aquae</i>	not common	Western
spheres	Western	Western
<i>Cryptomonas erosa</i>	Western	Western
<i>Chroomonas norstedtii</i>	not common	Western
<i>Merismopedia tenuissima</i>	not common	Western
<i>Pediastrum simplex</i> var. duodenarium	Central	Western
<i>Coelosphaerium naegelianum</i>	Central	Western
<i>Scenedesmus ecornis</i>	Central	Western
<i>Peridinium aciculiferum</i>	Central	Central
<i>Stephanodiscus</i>	Central	Western
<i>Asterionella formosa</i>	not common	Central
<i>Gymnodinium</i> sp.#2	-	Central
Haptophyte	-	Central

TABLE 42. Common species observed in either 1983 or 1984 but not both years, Lake Erie. 1983 data are from Makarewicz (1987).

1983	1984
<b>Bacillariophyta</b>	
Actinocyclus normanii f. subsalsa	Asterionella formosa
Melosira granulata	Melosira islandica
Rhizosolenia sp.	Stephanodiscus sp.
<b>Chlorophyta</b>	
Coelastrum microporum	Crucigenia rectangularis
Monoraphidium contortum	
Mougeotia sp.	
Scenedesmus ecornis	
Staurostrum paradoxum	
<b>Cyanophyta</b>	
Agmenellum quadruplicatum	Anacystis sp.
Oscillatoria subbrevis	
Oscillatoria tenuis	

TABLE 43. Importance of Asterionella formosa during the spring of 1984, Lake Erie. Sampling dates: 4/18, 4/20, 5/1/84.

Rank	Species	<u>Biovolume</u> (g/m <sup>3</sup> ) All Species
1	Asterionella formosa	0.162
2	Fragilaria crotonensis	0.160
3	Melosira islandica	0.123
4	Gymnodinium sp. #2	0.109

Rank	Species	<u>Abundance</u> (# /mL) Diatoms
1	Stephanodiscus sp.	238
2	Asterionella formosa	224
3	Fragilaria crotonensis	170
4	Stephanodiscus parvus	117

TABLE 44. Mean maximum biomass of selected common phytoplankton species in 1970 and 1983, Lake Erie. Data from Munawar and Munawar (1976) and this study. 1970 data - graphical accuracy. Percent reduction is from 1970 to 1984.

	BASIN	1970 g/m <sup>3</sup>	1983 g/m <sup>3</sup>	1984 g/m <sup>3</sup>	Percent Reduction
<i>Actinocyclus</i> <i>normanii</i>	Western	4.7	0.30	0.05	99
<i>Stephanodiscus</i> <i>niagarae</i>	Eastern	1.4	1.05	0.22	84
	Central	2.3	2.19	0.23	90
	Western	0.6	0.12	0.17	72
<i>Stephanodiscus</i> <i>tenuis</i>	Western	1.8	0.001	0.002	99
<i>Stephanodiscus</i> <i>binderanus</i>	Western	0.5	0.11	0.04	92
<i>Fragilaria</i> <i>crotonensis</i>	Eastern	1.0	0.15	0.45	54
	Central	3.4	0.11	0.16	95
	Western	7.9	0.18	0.29	96
<i>Fragilaria</i> <i>capucina</i>	Central	2.4	0.02	0.03	99
	Eastern	0.4	0.04	0.01	99
<i>Peridinium</i> <i>aciculiferum</i>	Central	0.2	0.06	0.18	10
	Eastern	1.0	0.05	0.03	95
<i>Ceratium</i> <i>hirundinella</i>	Central	1.8	0.35	0.13	93
	Eastern	2.0	0.31	0.35	83
<i>Rhodomonas</i> <i>minuta</i>	Eastern	1.6	0.04	0.05	97
	Central	0.4	0.10	0.14	65
<i>Cryptomonas</i> <i>erosa</i>	Western	2.0	0.63	0.40	37
<i>Pediastrum</i> <i>simplex</i>	Central	0.4	0.06	0.00	100
<i>Staurostrum</i> <i>paradoxum</i>	Central	0.4	0.07	0.00	100
<i>Aphanizomenon</i> <i>flos-aquae</i>	Western	2.0	0.10	0.09	96



Table 45. Distribution of indicator diatom species in the western basin of Lake Erie. The classification scheme of Tarapchak and Stoermer (1976) was utilized. Only diatoms contributing 5% or more of the biomass for a cruise are classified.  $M_1$  = mesotrophic but intolerant of nutrient enrichment,  $M_2$  = mesotrophic and tolerant of moderate nutrient enrichment, E = eutrophic. 1970 data are from Munawar and Munawar (1976). 1978 data are from Devault and Rockwell (1986).

	$M_1$	$M_2$	E	$M_1+M_2/E$
1970	0	1	5	0.2
1978	0	3	3	1.0
1983	1	2	3	1.0
1984	3	2	2	2.5

Table 46. Trophic status of the western, central and eastern basins of Lake Erie in 1970 and 1983/84. The classification scheme of Munawar and Munawar (1982) is used. 1970 data is from Munawar and Munawar (1982). Based on average biomass of basins in 1983 and 1984.

	1970	1983 + 84
Eastern Basin	mesoeutrophic	oligotrophic
Central Basin	mesoeutrophic	mesotrophic
Western Basin	eutrophic	mesotrophic

Table 47. Relative abundance of zooplankton in Lake Erie.

	<u>Percent Biomass</u>		<u>Percent Abundance</u>	
	1983	1984	1983	1984
Rotifera	N	13.6	69.2	80.1
Cladocera	O C			
	T A	40.5	6.0	3.2
	L			
Copepoda nauplii	C	12.3	15.8	10.4
Cyclopoida	U			
	L	17.1	5.4	3.9
Calanoida	A			
	T	16.5	3.7	2.5
Harpacticoida	E			
	D	<.1	<.1	<.1
Amphipoda		<.1	0.0	<.1

TABLE 48. Summary of common zooplankton species occurrence in Lake Erie during 1984. Values are from the short zooplankton hauls only. Species were arbitrarily classified as common if they accounted for >0.1% of the total abundance or 1.0% of the total biomass, with the exception of rotifers. Rotifer species were considered common if they accounted for >1.0% of the total abundance.

Taxon	Maximum Density # /m <sup>3</sup>	Average Density # /m <sup>3</sup>	% of Total Density	Mean Biomass ug/m <sup>3</sup>	% of Total Biomass
=====					
COPEPODA					
Copepoda - nauplii	79012	16275	10.35	6510	12.34
Cyclopoida					
Cyclopoid - copepodite	13367	3625	2.31	2614	4.95
Cyclops bicuspidatus					
thomasi	4519	790	.50	3637	6.89
Mesocyclops - copepodite	6311	954	.61	758	1.44
Mesocyclops edax	3095	413	.26	1608	3.05
Tropocyclops prasinus					
mexicanus	1407	234	.15	255	.48
Calanoida					
Diaptomus - copepodite	20178	2652	1.69	4249	8.05
Diaptomus oregonensis	7731	890	.57	3631	6.88
		TOTAL	16.44		44.08
CLADOCERA					
Bosmina longirostris	4772	710	.45	832	1.58
Chydorus sphaericus	6675	157	.10	126	.24
Daphnia galaeta mendotae	21410	1932	1.23	7506	14.22
Daphnia pulicaria	3752	492	.31	7784	14.75
Daphnia retrocurva	6903	287	.18	982	1.86
Eubosmina coregoni	11215	1209	.77	2417	4.58
Holopedium gibberum	807	63	.04	754	1.43
Leptodora kindtii	623	35	.02	627	1.19
		TOTAL	3.11		39.85
ROTIFERA					
Ascomorpha ovalis	57498	6159	3.92	77	.15
Asplanchna priodonta	52038	1806	1.15	1582	3.00
Brachionus sp.	157414	3418	2.17	203	.38
Conochilus unicornis	57762	3404	2.17	37	.07
Keratella cochlearis	40170	7726	4.91	29	.06
Keratella crassa	37236	1575	1.00	77	.15
Keratella earlinae	42931	1831	1.16	65	.12
Notholca foliacea	56316	2825	1.80	74	.14
Notholca laurentiae	93031	5125	3.26	363	.69
Notholca squamula	348455	17392	11.06	347	.66
Polyarthra dolichoptera	61171	4430	2.82	208	.39
Polyarthra major	102788	7768	4.94	711	1.35
Polyarthra remata	18399	2537	1.61	44	.08
Polyarthra vulgaris	340262	35357	22.49	1597	3.03
Synchaeta sp.	340262	14864	9.46	1115	2.11
		TOTAL	73.93		12.37
			=====		=====
			93.48		96.30

TABLE 49. Occurrence of eutrophic zooplankton indicator species in Lake Erie, 1984. Values are in number/m<sup>3</sup>.

	BASIN		
	Western	Central	Eastern
<i>Brachionus angularis</i>	177	0	0
<i>B. budapestinen</i> *	92	0	0
<i>B. calyciflorus</i>	97	0	0
<i>B. caudatus</i>	81	0	0
<i>Filinia longiseta</i>	459	2.8	0
<i>Keratella cochlearis</i> f. <i>tecta</i>	2062	9.2	0
<i>Trichocerca cylindrica</i>	397	0	0
<i>T. elongata</i> *	907	0	0
<i>T. multicornis</i>	477	42	0
<i>T. pusilla</i>	36	0	0

\*Not listed as eutrophic species by Gannon and Stemberger (1978).

TABLE 50. Ratio of calanoids to cladocerans plus cyclopoids in Lake Erie, 1983 and 1984.

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	WESTERN BASIN	CENTRAL BASIN	EASTERN BASIN	MEAN
1983	0.19	0.31	0.45	0.32
1984	0.27	0.42	0.36	0.35

Table 51. Correlation (r) of phytoplankton abundance with total phosphorus concentration and zooplankton abundance within individual cruises (11 stations) in Lake Erie, 1984. N.O.=not observed.

	Daphnia pulicaria	Daphnia spp.	Rotifera	Calanoida	Total Phosphorus
4/18-19	N.O.	.535	.714	.343	.801
5/1-2	N.O.	-.941	-.771	-.922	-.811
8/5-6	-.509	-.079	.021	-.534	.756
8/19-20	-.548	.061	.929	-.383	.910
12/4-5	N.O.	-.448	.097	-.345	.505

Table 52. Turbidity levels in 1978 and 1984, Lake Erie. 1978 values represent graphical accuracy.

	1978	1984
	mean±S.E.	mean±S.E.
Western	4.2±1.5	2.66±.43
Central	0.7	0.40±.04
Eastern	0.5	0.52±.09



## Station Locations Lake Michigan - Main Lake



FIGURE 1. Lake Michigan plankton sampling stations, 1984-85

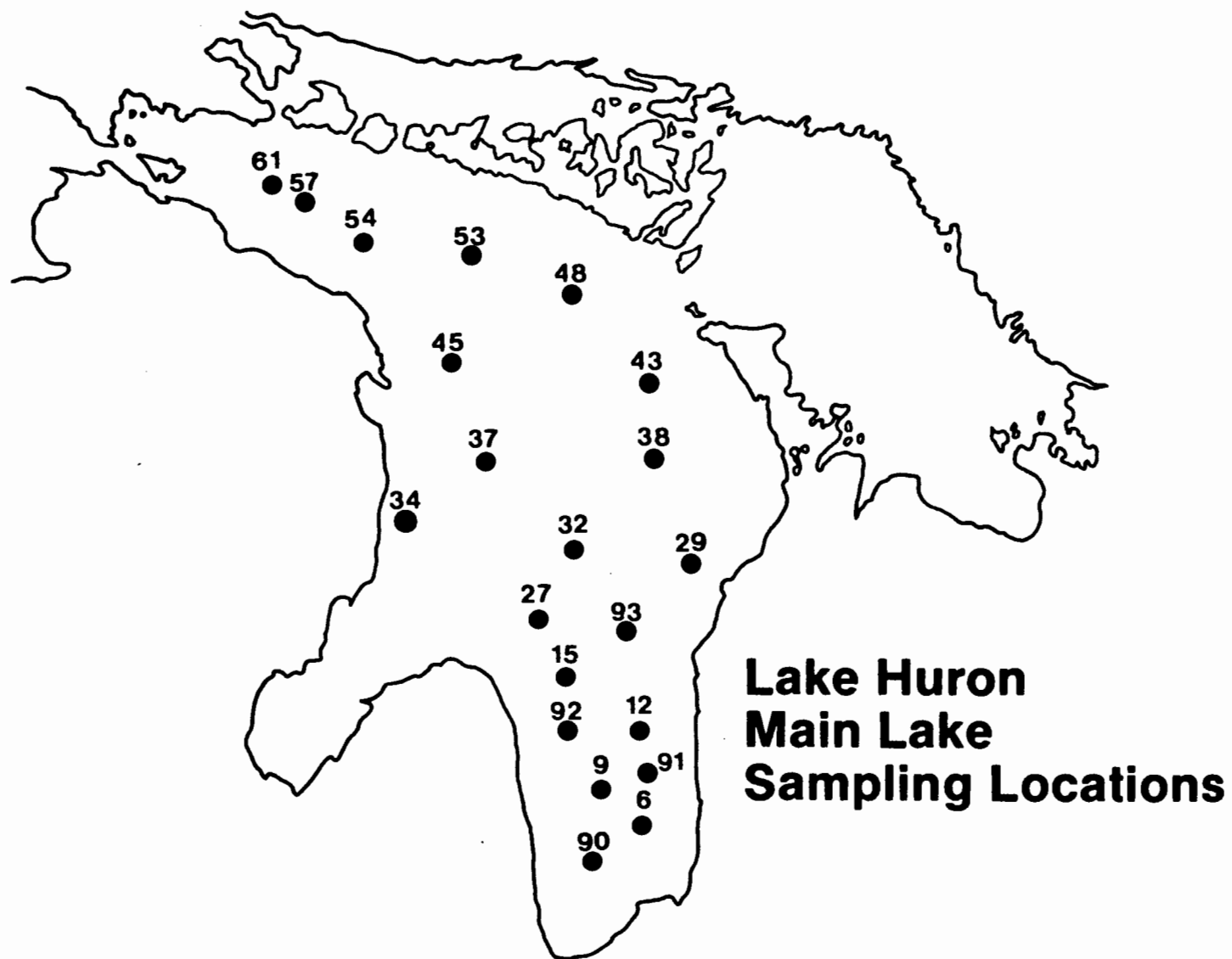


FIGURE 2. Lake Huron plankton sampling stations, 1984-85. ;

# Lake Erie Main Lake Sampling Station

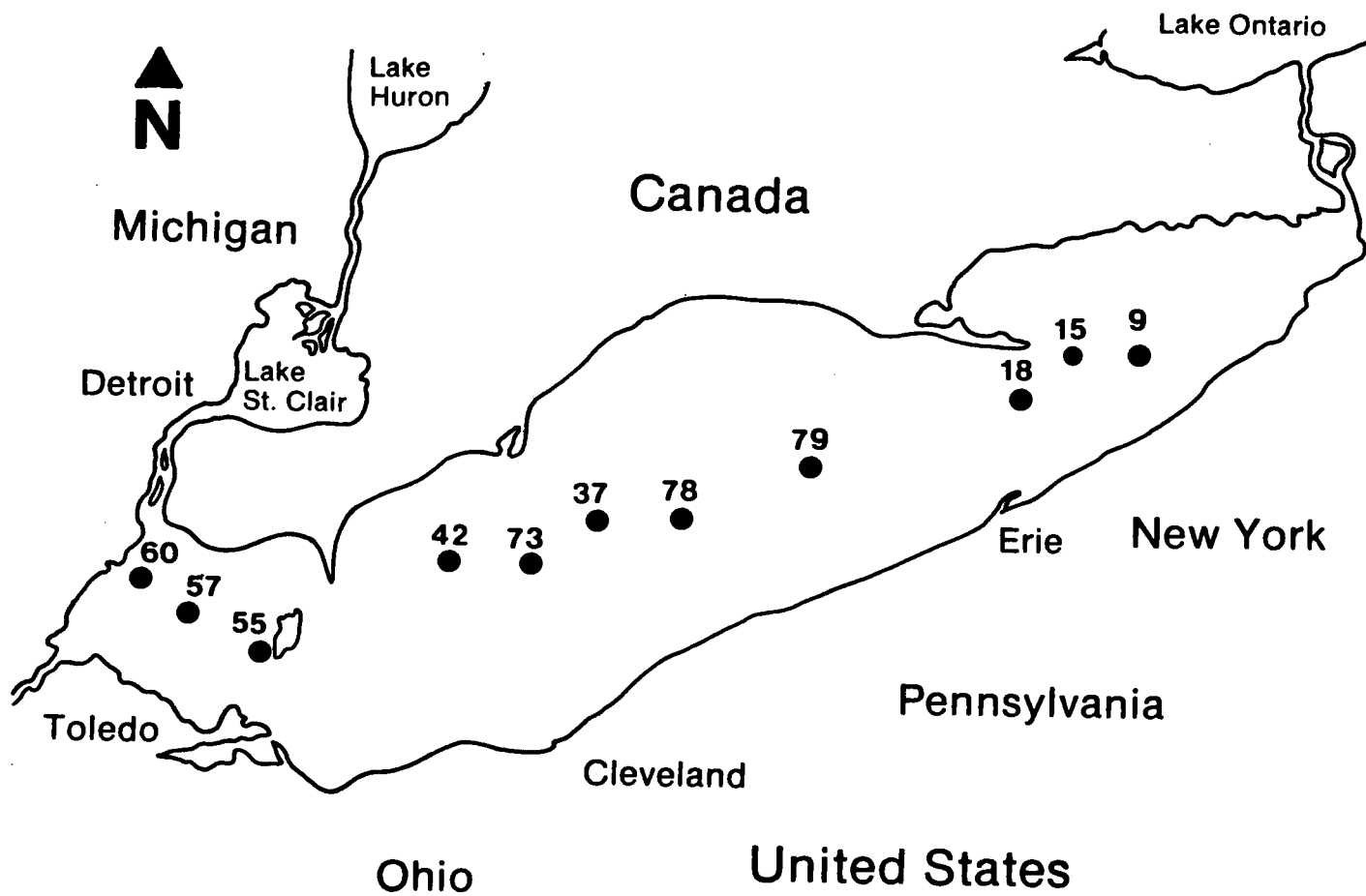


FIGURE 3. Lake Erie plankton sampling stations, 1984-85.

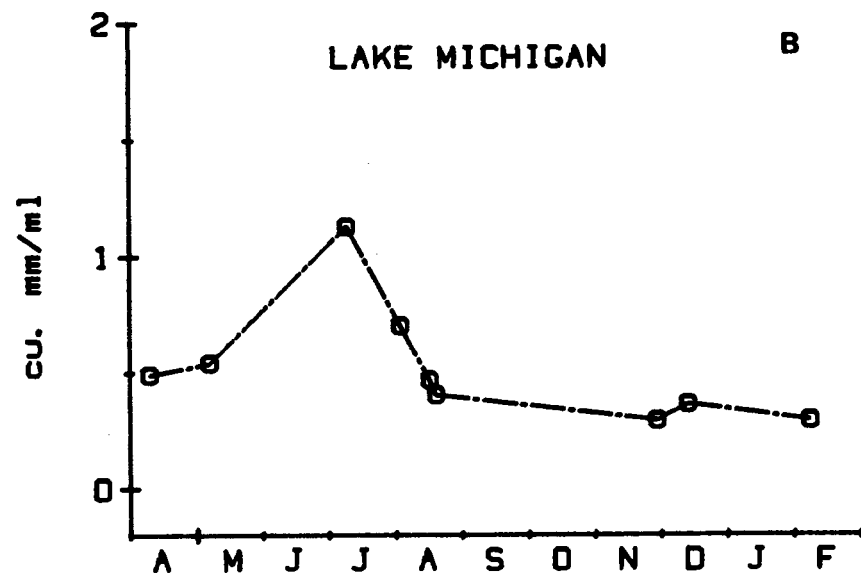
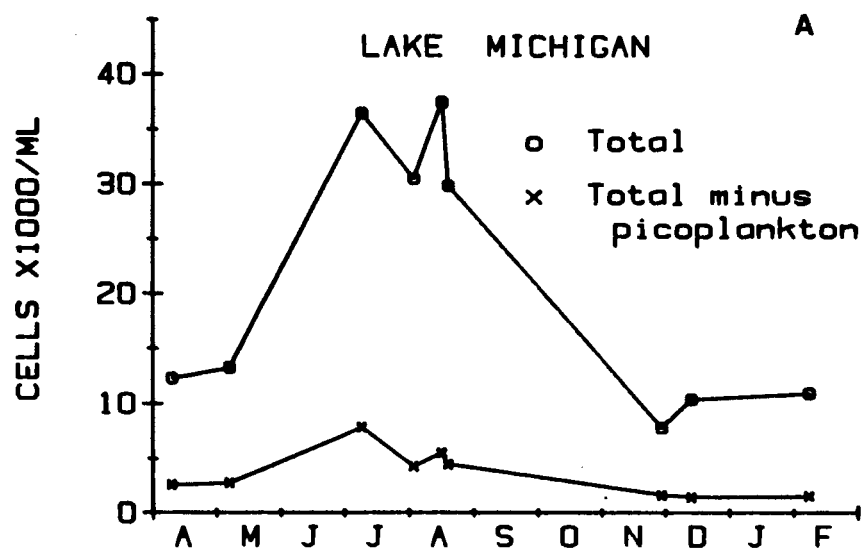


FIGURE 4. Seasonal phytoplankton abundance (4a) and biovolume (4b) trends in Lake Michigan, 1984-85.

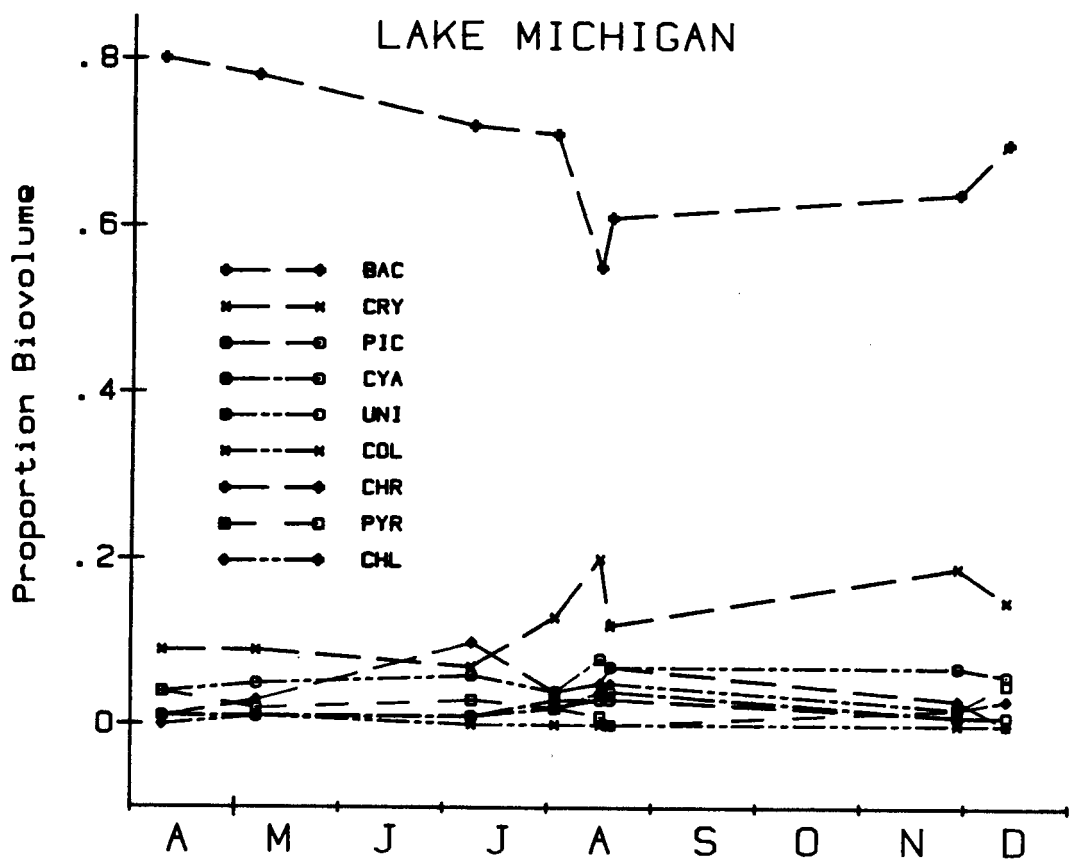


FIGURE 5. Seasonal distribution of algal divisions in Lake Michigan. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Col=colorless flagellates, Cry=Cryptophyta, Cya=Cyanophyta, Pic=picoplankton, Pyr=Pyrrhophyta, Uni=unidentified flagellates, 1984-85.

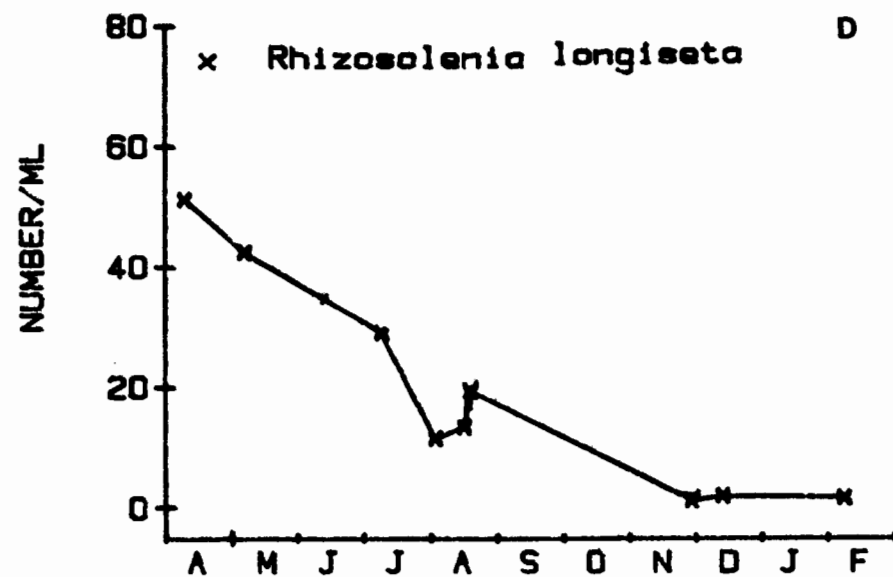
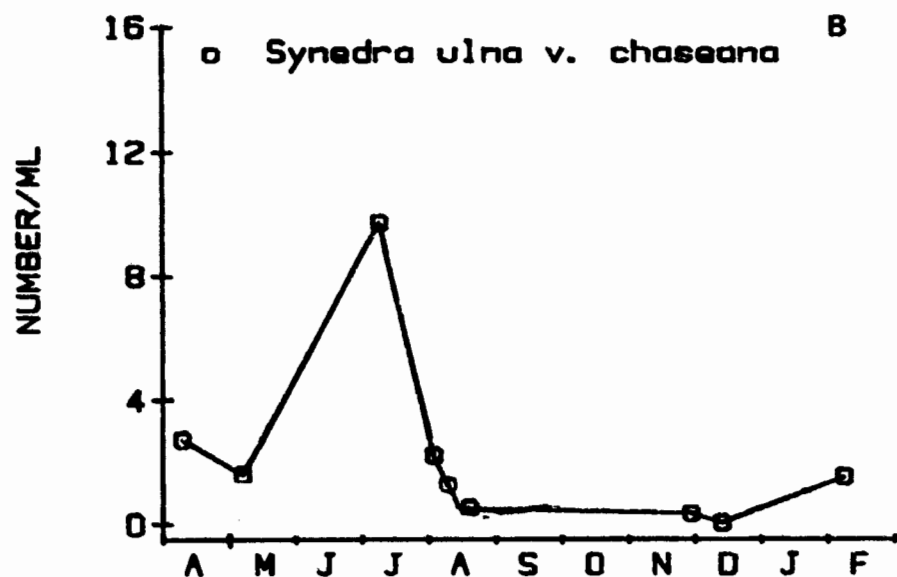
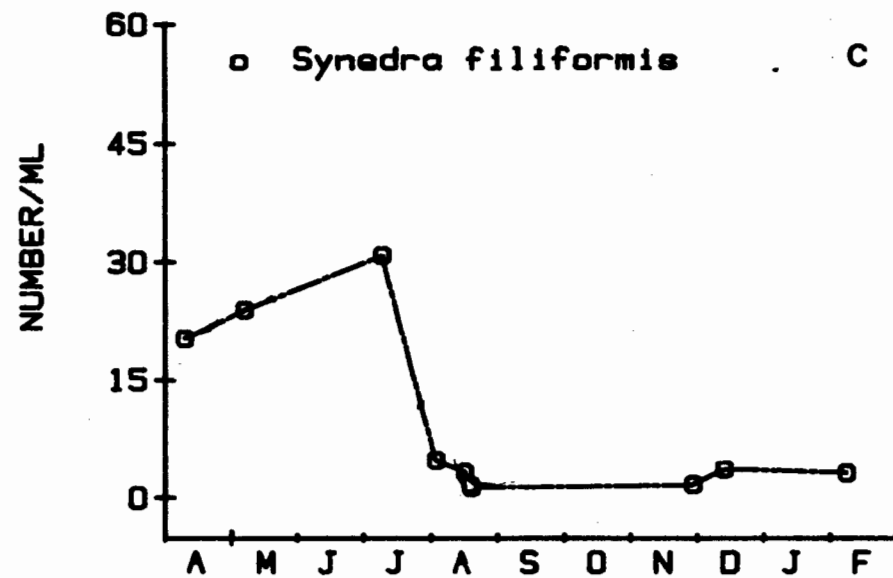
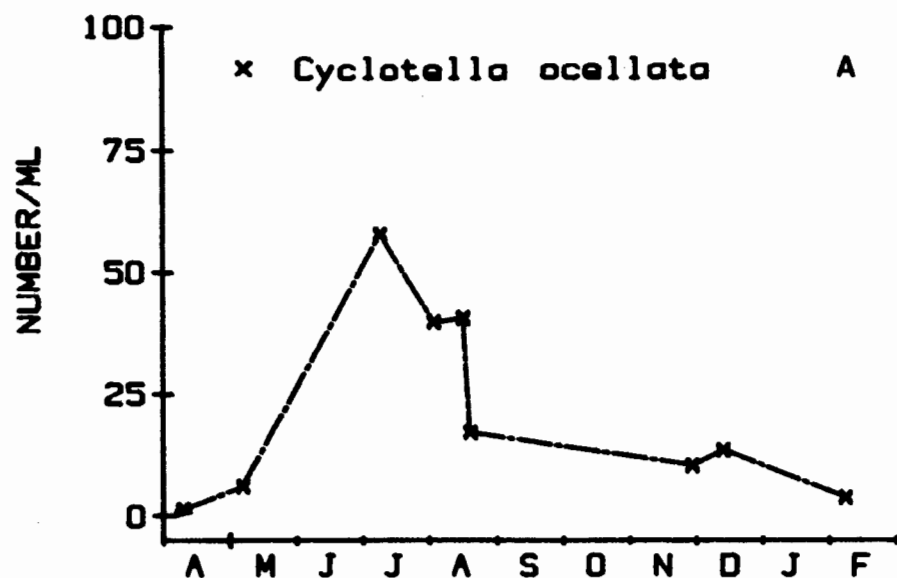


FIGURE 6. Mean seasonal distribution of a) *Cyclotella ocellata*, b) *Synedra ulna* v. *chaseana*, c) *Synedra filiformis* and d) *Rhizosolenia longiseta*, Lake Michigan

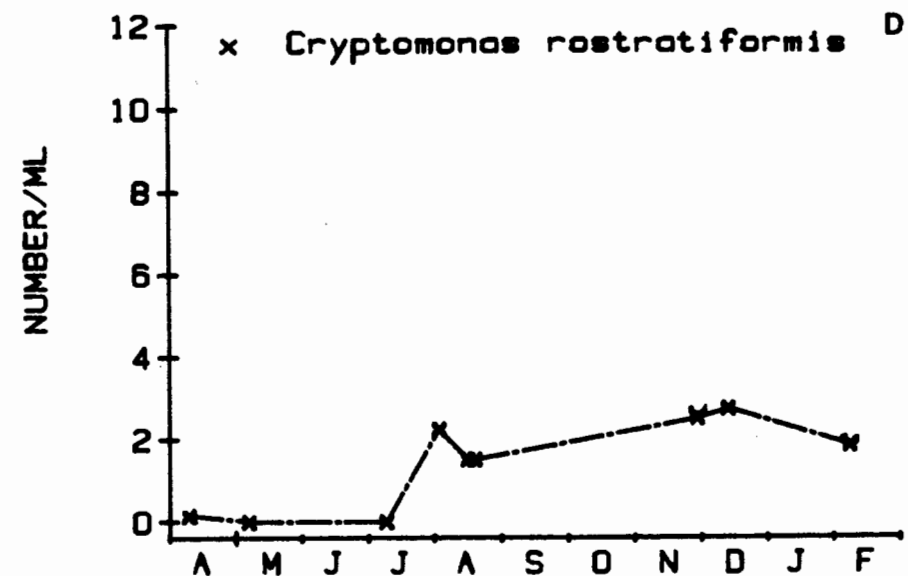
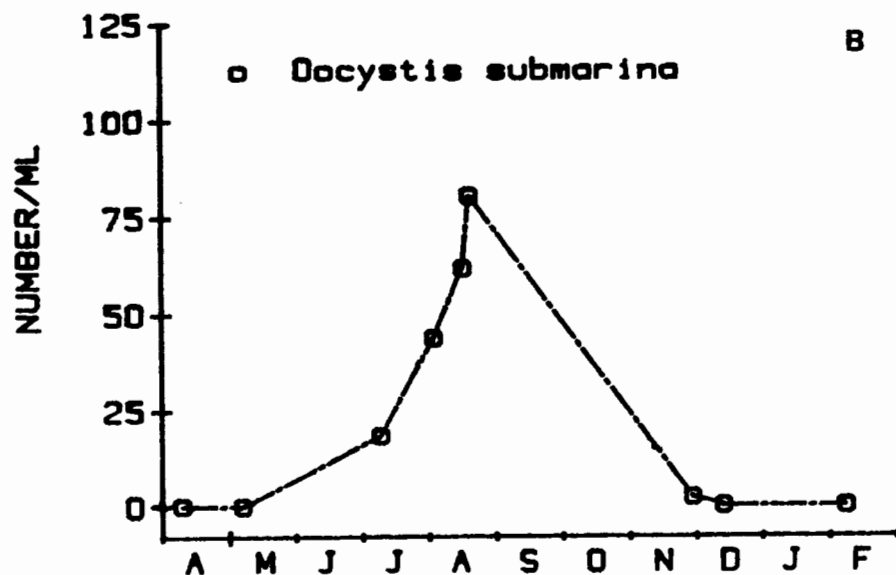
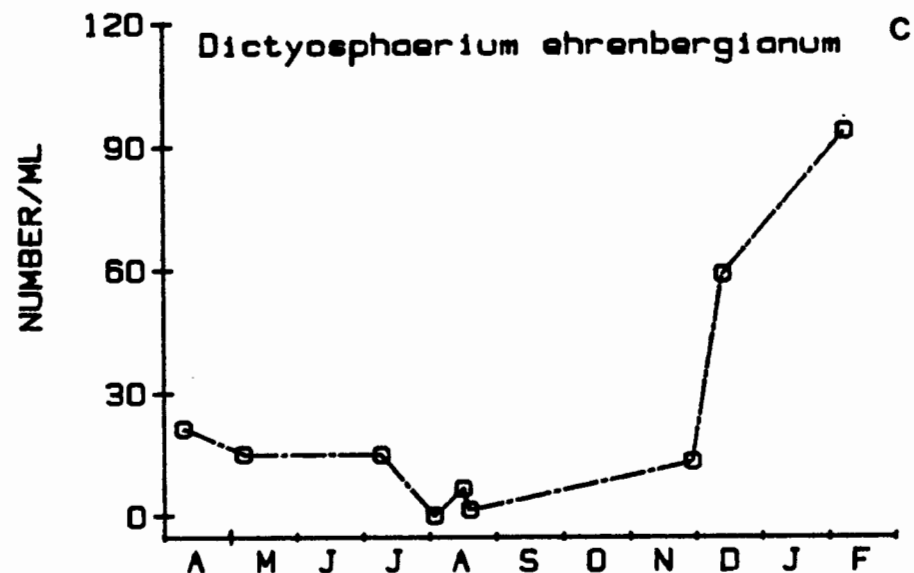
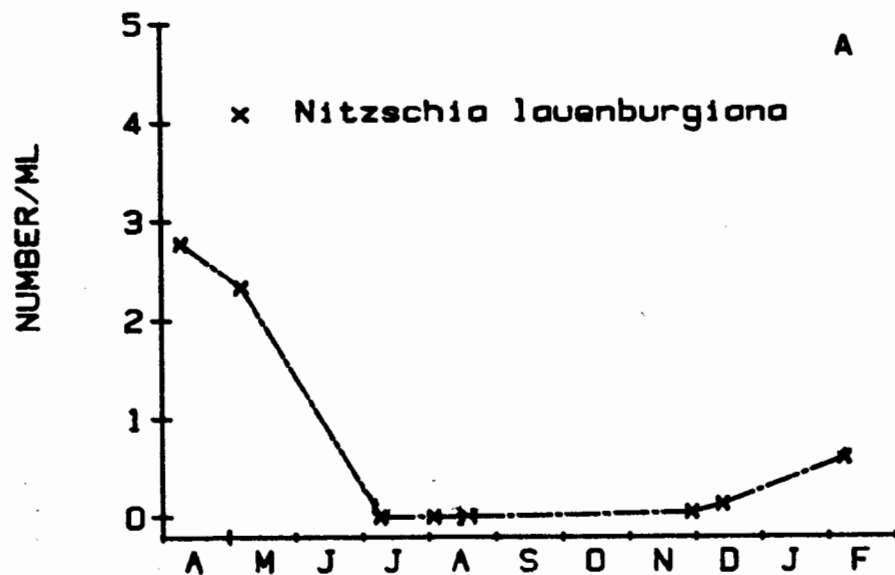


FIGURE 7. Mean seasonal distribution of a) *Nitzschia lauenburgiana*, b) *Oocystis submarina*, c) *Dictyosphaerium ehrenbergianum* and d) *Cryptomonas rostratiformis*, Lake Michigan

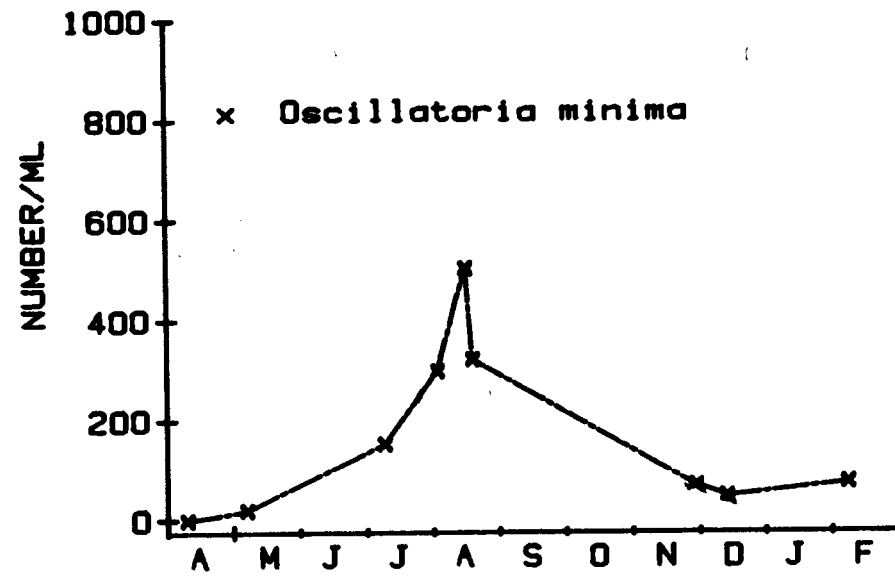


FIGURE 8. Mean seasonal distribution of *Oscillatoria minima*, Lake Michigan



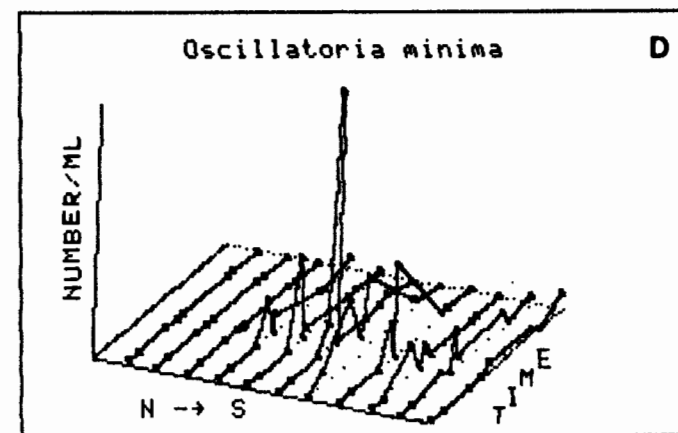
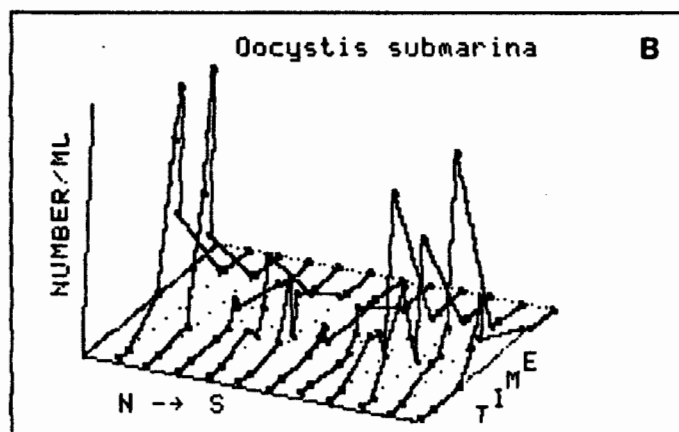
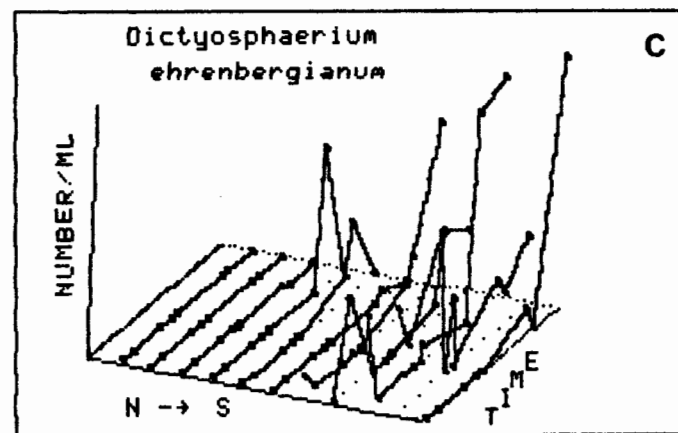
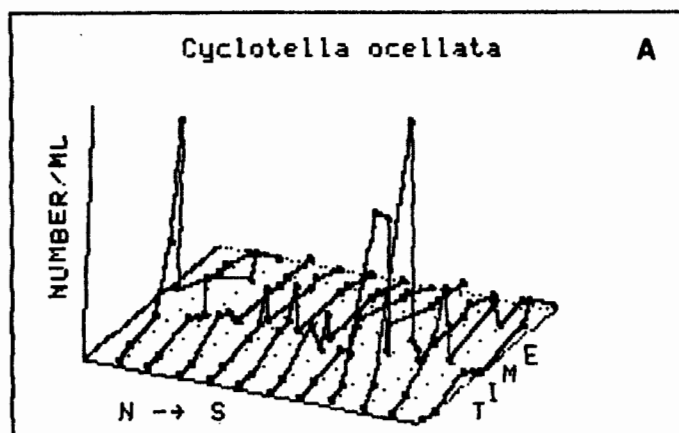


FIGURE 9. Seasonal and geographical distribution of a) *Cyclotella ocellata*, b) *Oocystis submarina*, c) *Dictyosphaerium ehrenbergianum* and d) *Oscillatoria minima*, Lake Michigan

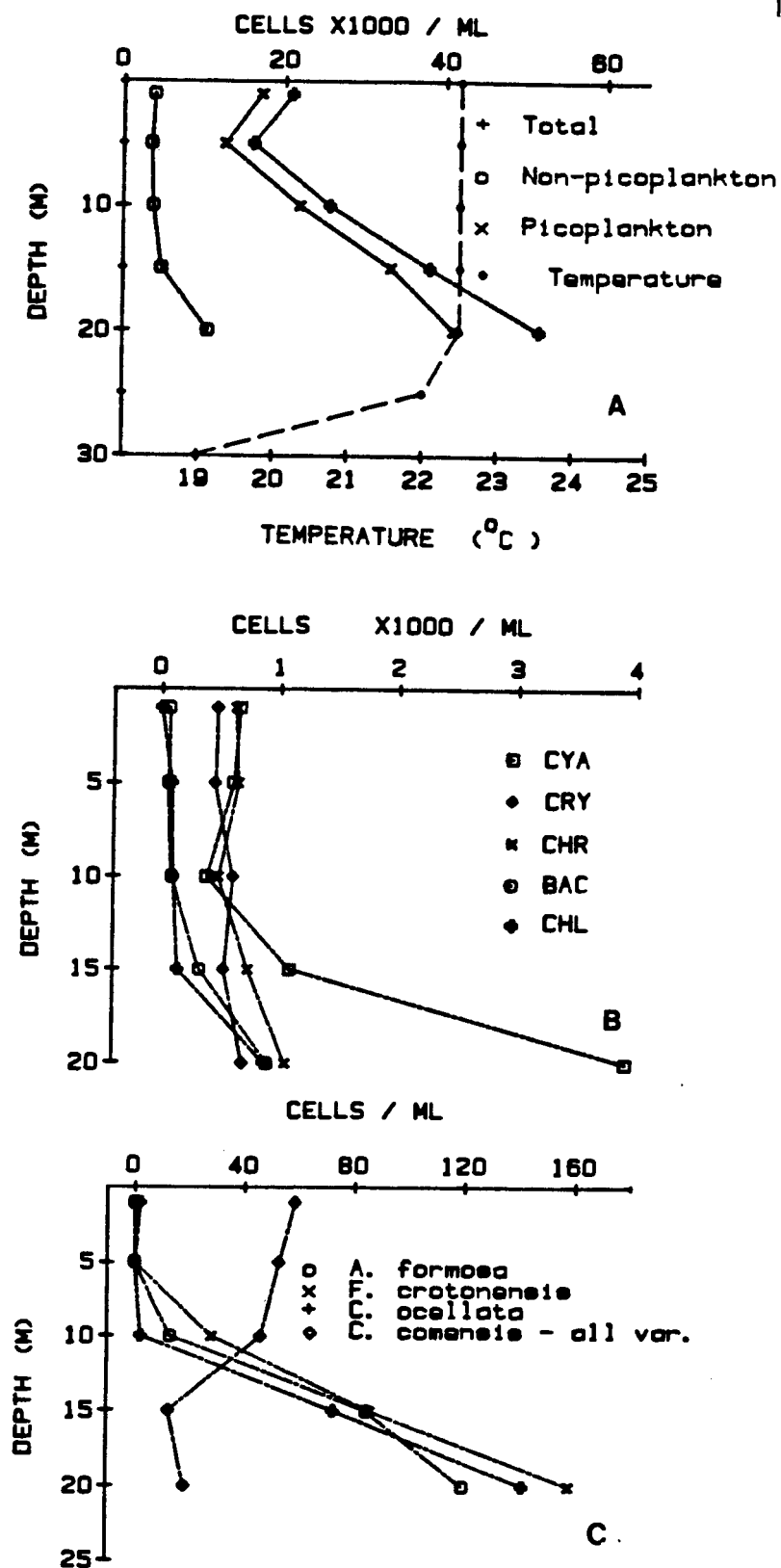


FIGURE 10. Vertical distribution of phytoplankton at Station 47, 15 August 1984, Lake Michigan

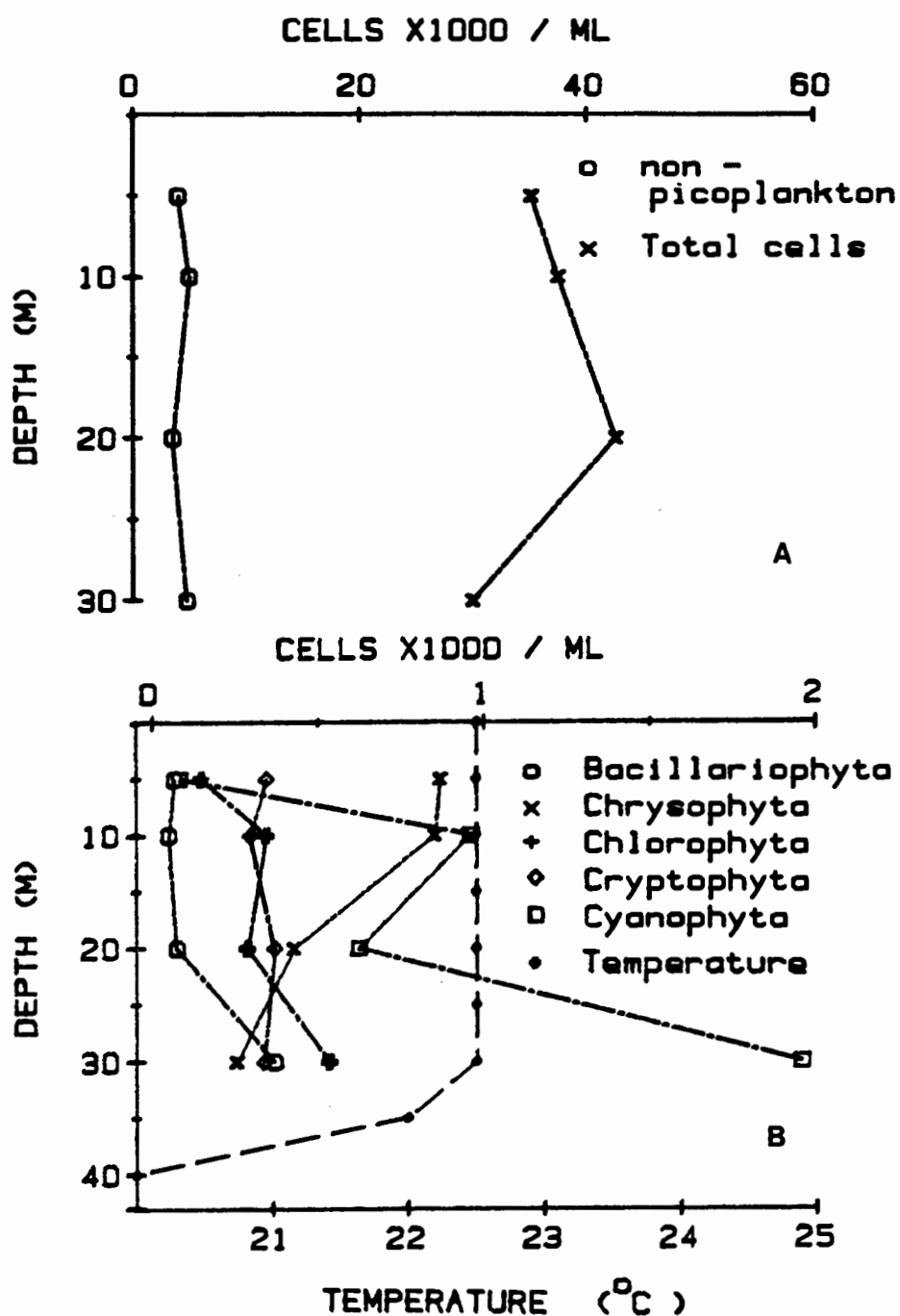


FIGURE 11. Vertical distribution of phytoplankton at Station 18, 15 August 1984, Lake Michigan

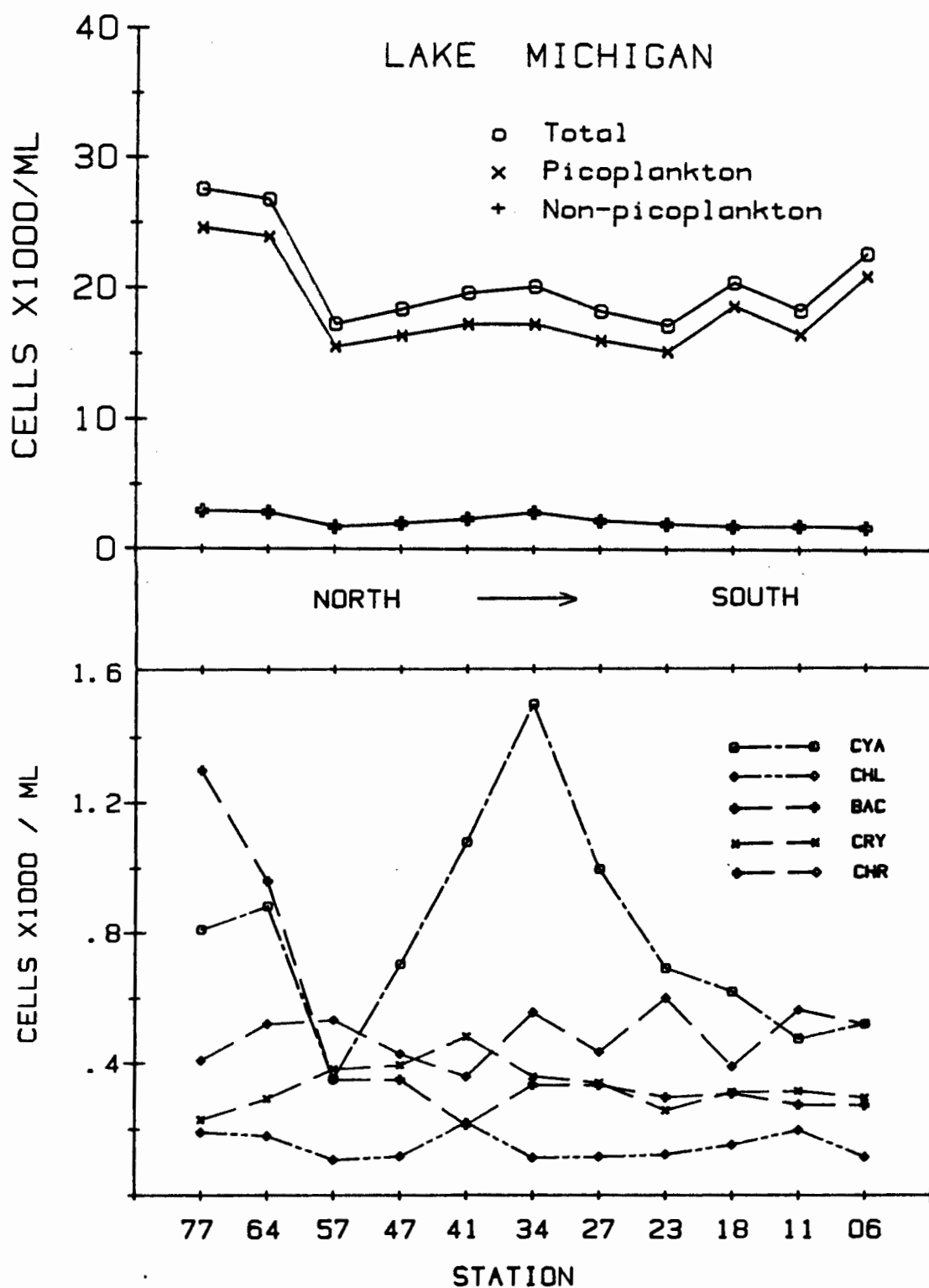
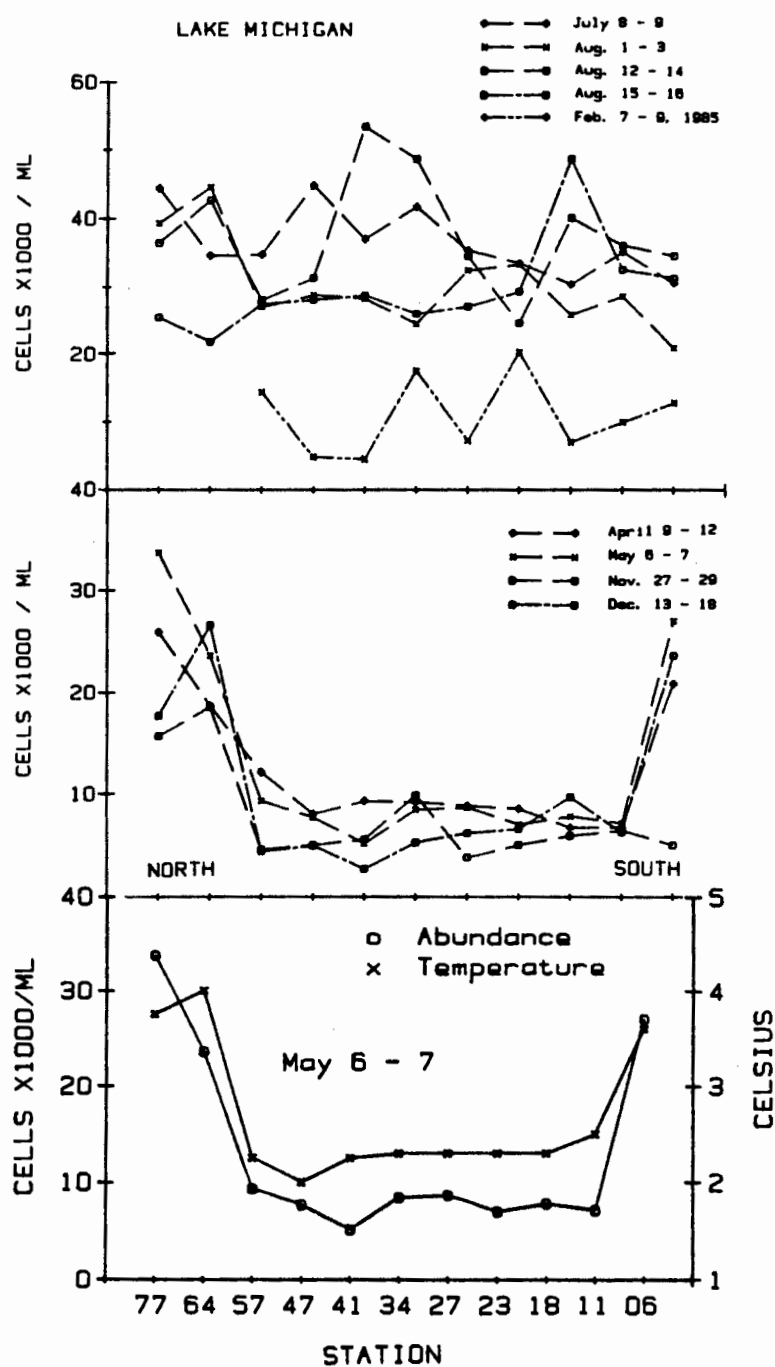


FIGURE 12. Annual geographical distribution of major algal divisions in Lake Michigan. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Cry=Cryptophyta, Cya=Cyanophyta, Pic=picoplankton, Pyr=Pyrrhophyta, 1984-85.



**FIGURE 13.** Geographical distribution of phytoplankton abundance on all cruises, Lake Michigan, 1984-85.

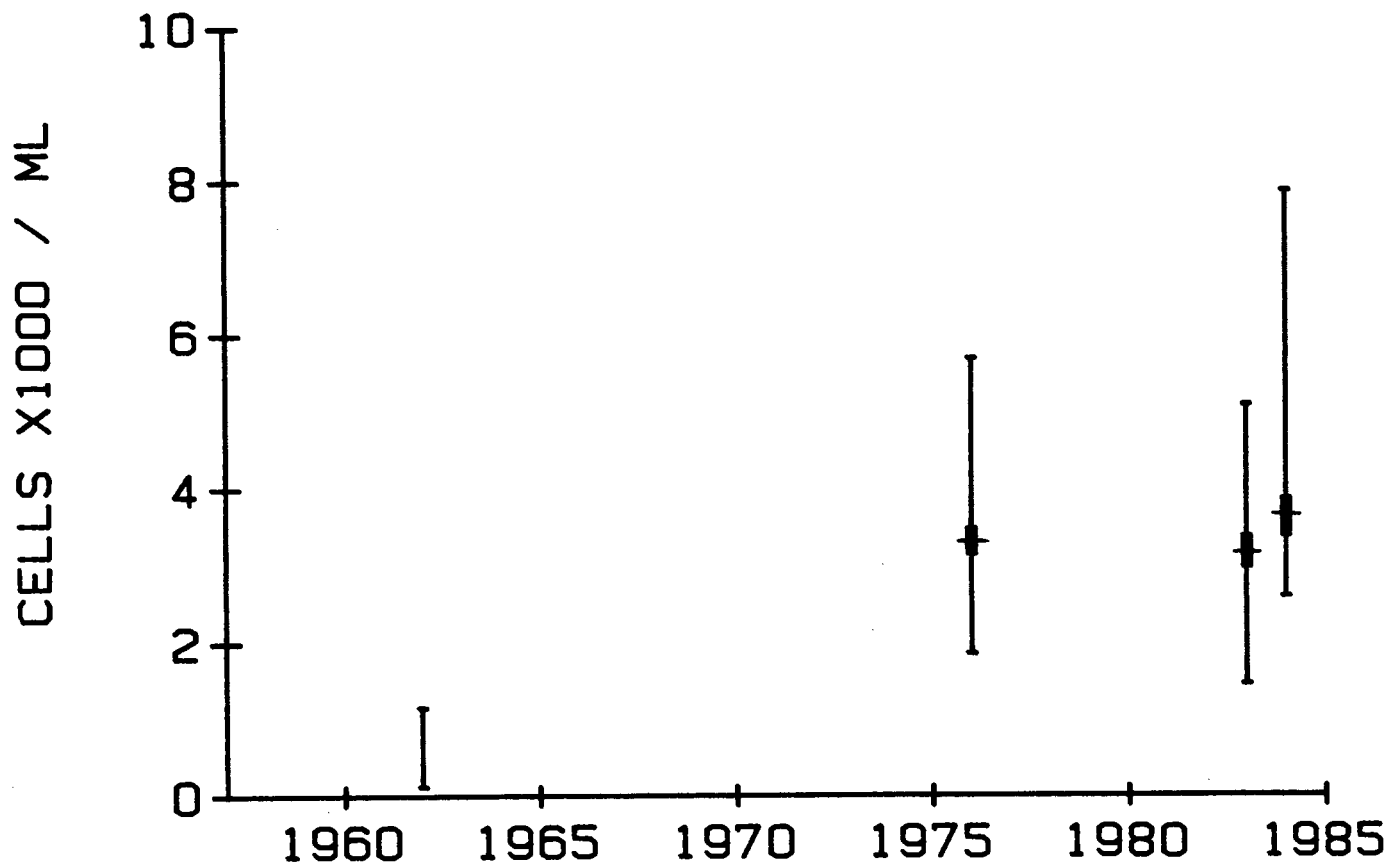


FIGURE 14. Historical abundance of phytoplankton in Lake Michigan. Horizontal bars are the mean. Wide vertical lines are the standard error. Thin vertical lines are the range. Data are from Stoermer and Kopczynska (1967a and b), Rockwell et al. (1980), Makarewicz (1987) and this study.

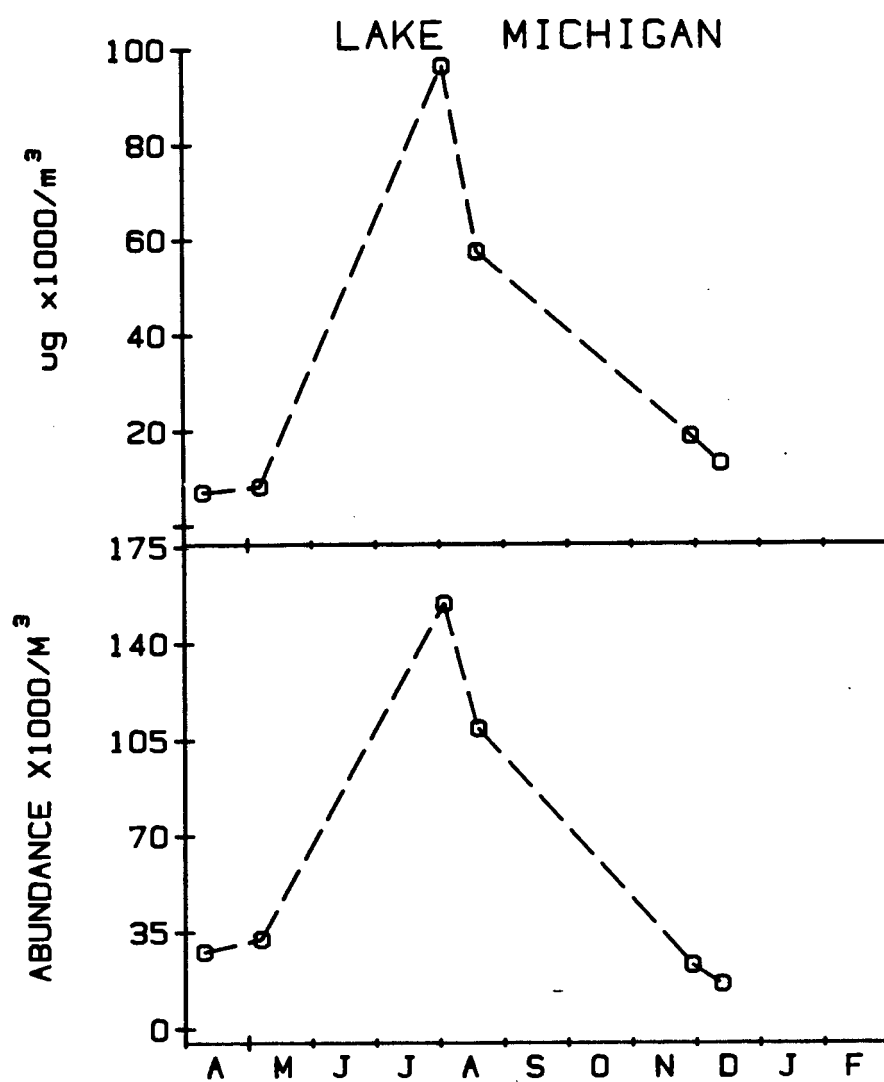


FIGURE 15. Seasonal zooplankton abundance in Lake Michigan, 1984.

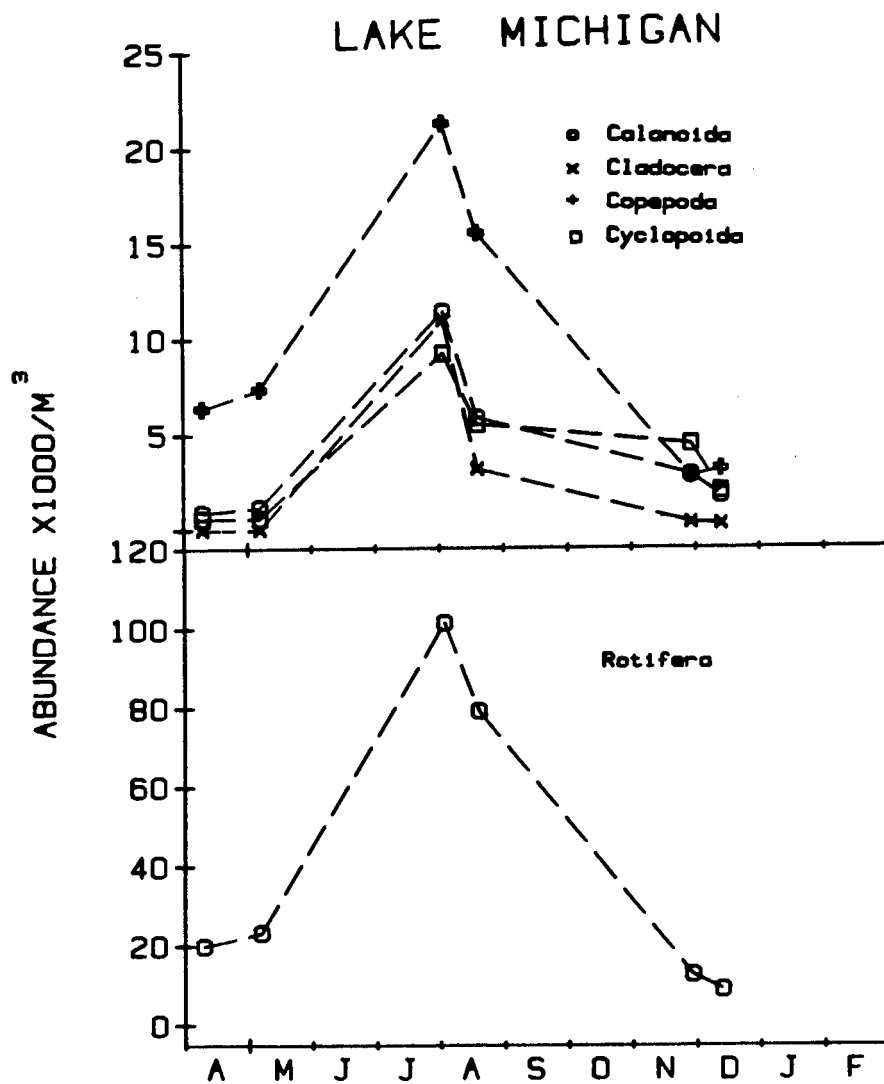


FIGURE 16. Seasonal fluctuation (numerical) of zooplankton groups in Lake Michigan, 1984. Copepoda refers to the nauplius stage of the Copepoda.



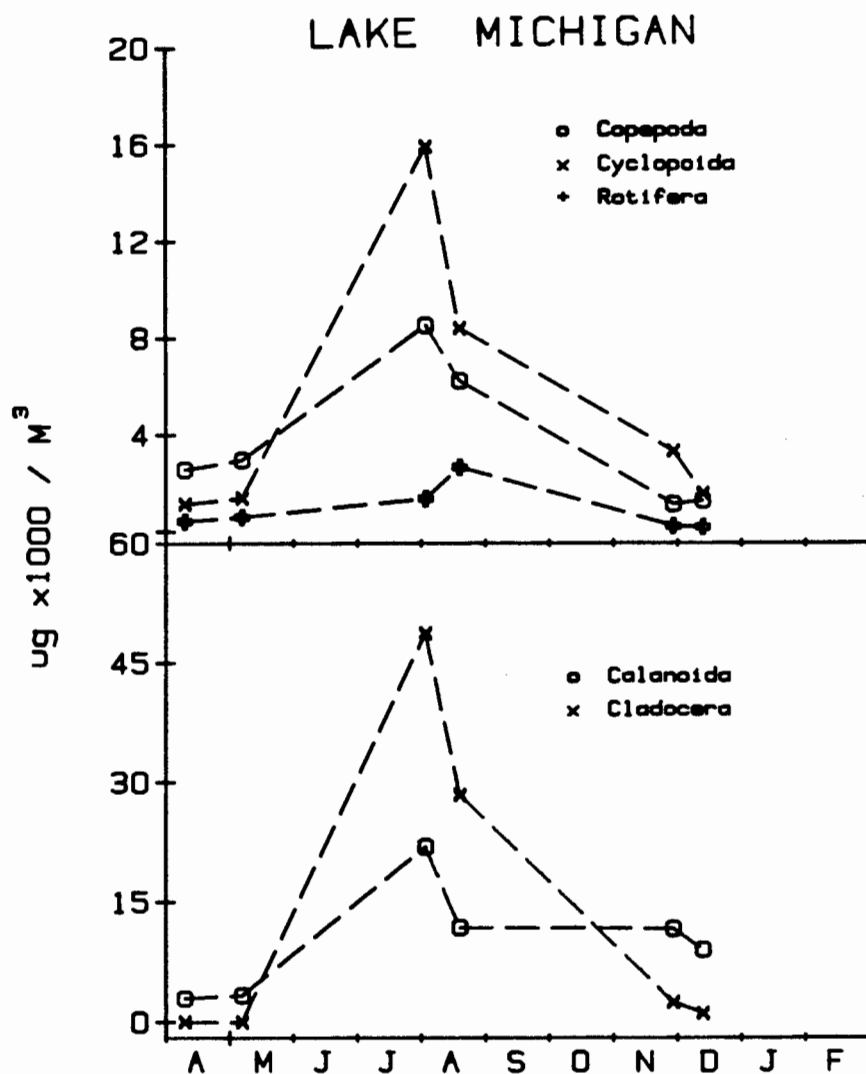


FIGURE 17. Seasonal fluctuation (biomass) of zooplankton groups in Lake Michigan, 1984. Copepoda refers to the nauplius stage of the Copepoda.

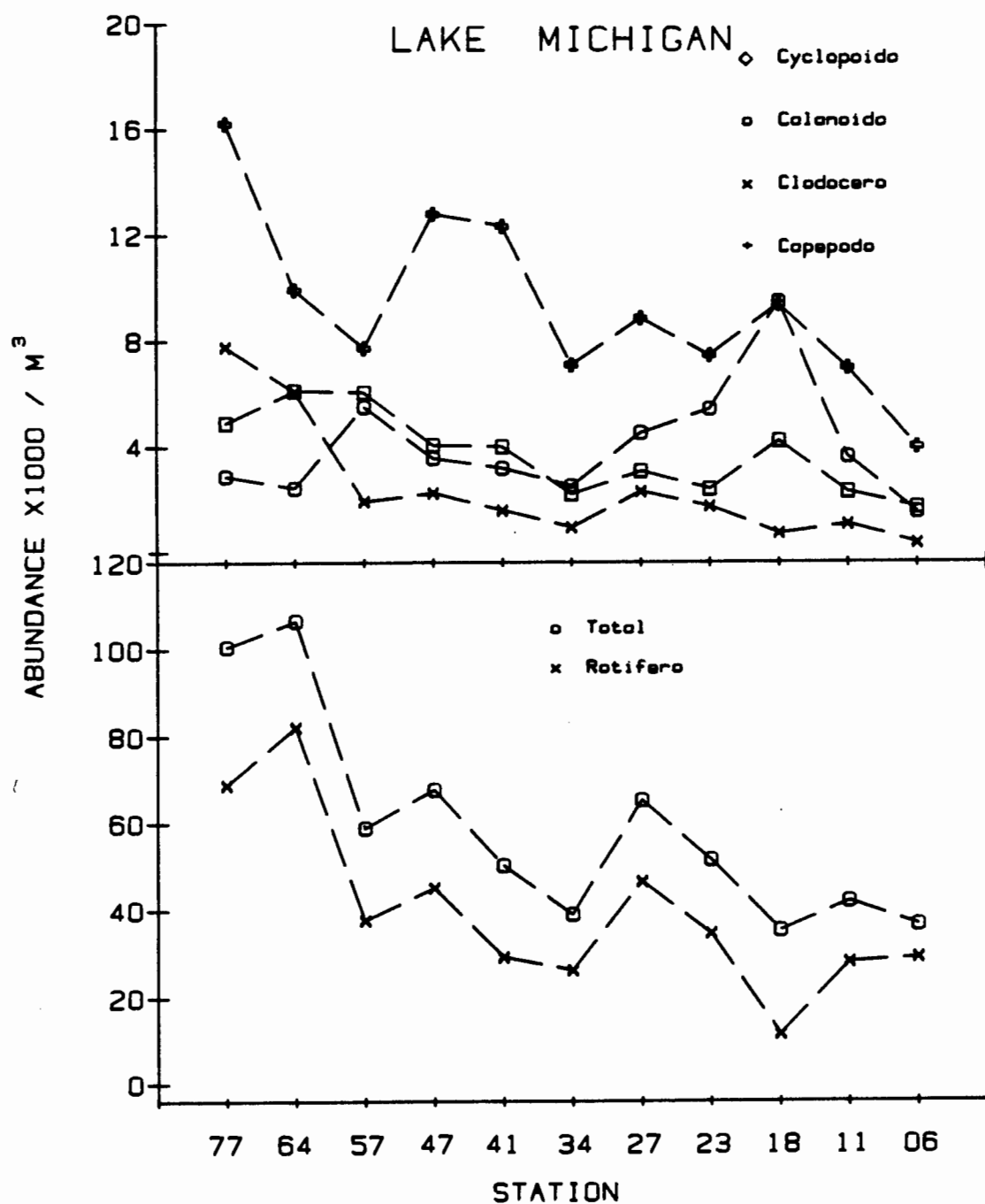


FIGURE 18. Geographical distribution (numerical) of major zooplankton groups in Lake Michigan, 1984. Copepoda = Copepoda nauplius.

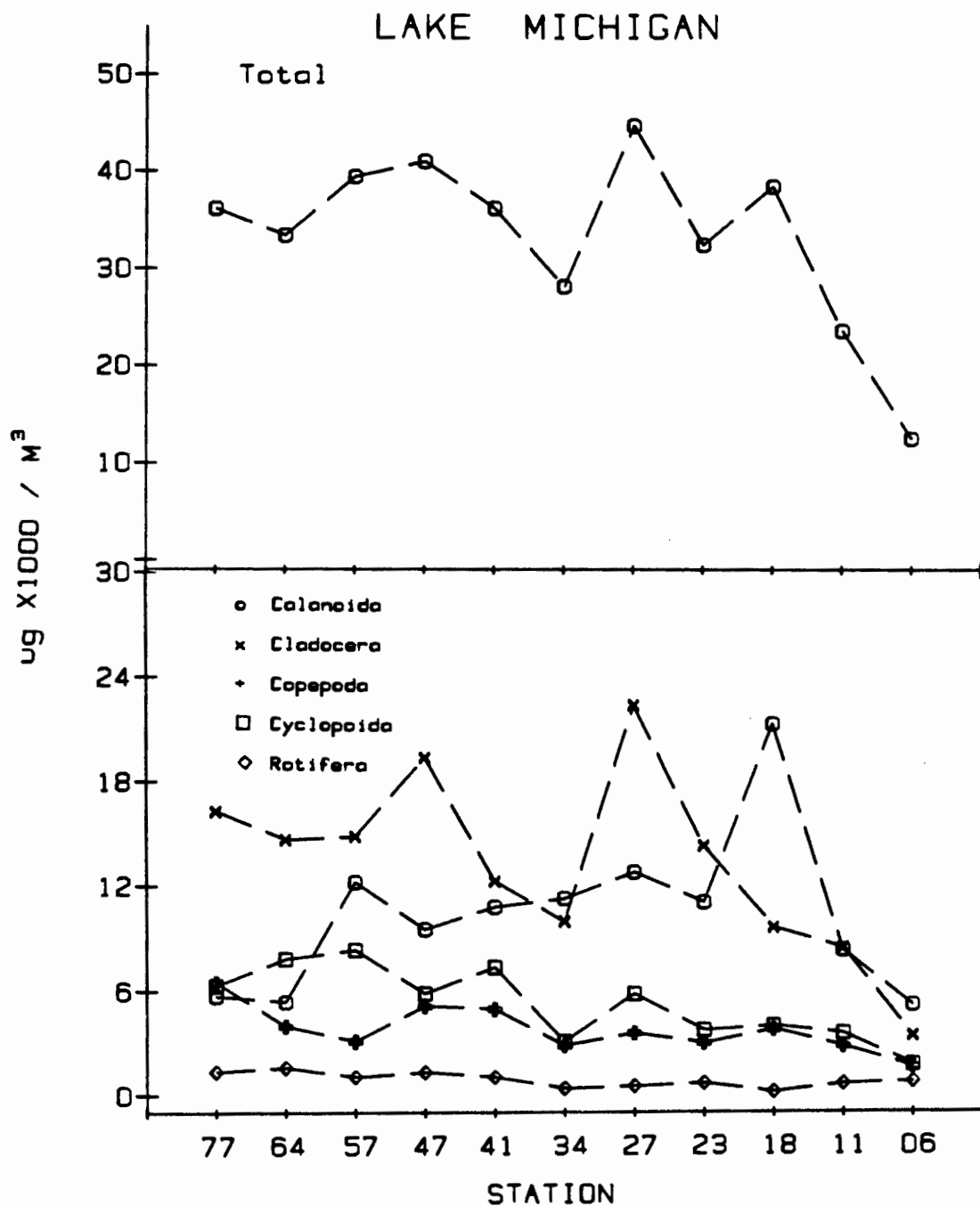


FIGURE 19. Geographical distribution (biomass) of major zooplankton groups in Lake Michigan, 1984. Copepoda = Copepoda nauplius.

## LAKE MICHIGAN

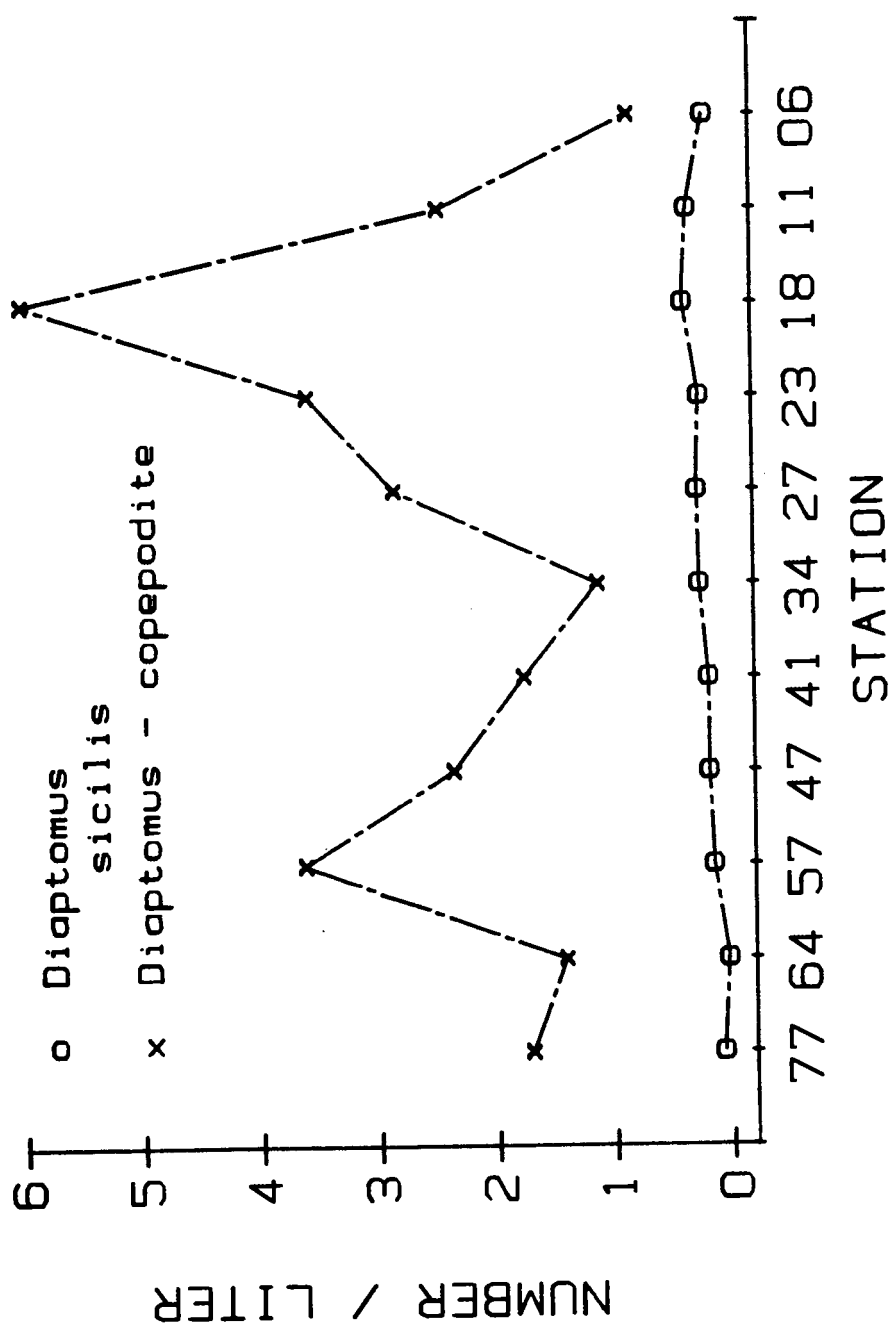


FIGURE 20. Geographical distribution of *Diaptomus sicilis* in Lake Michigan, 1984.

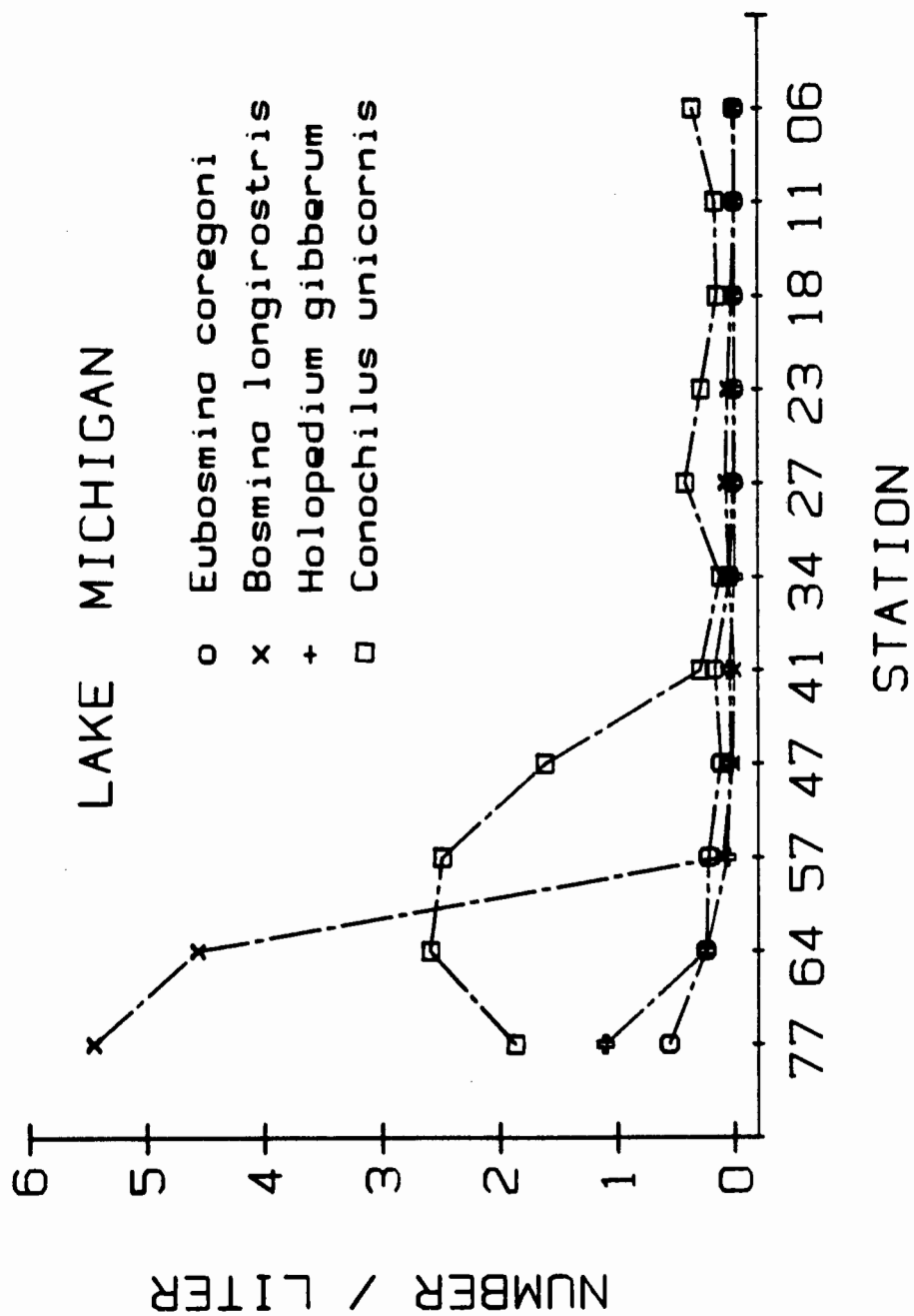


FIGURE 21. Geographical distribution of selected zooplankton in Lake Michigan, 1984.

# LAKE MICHIGAN

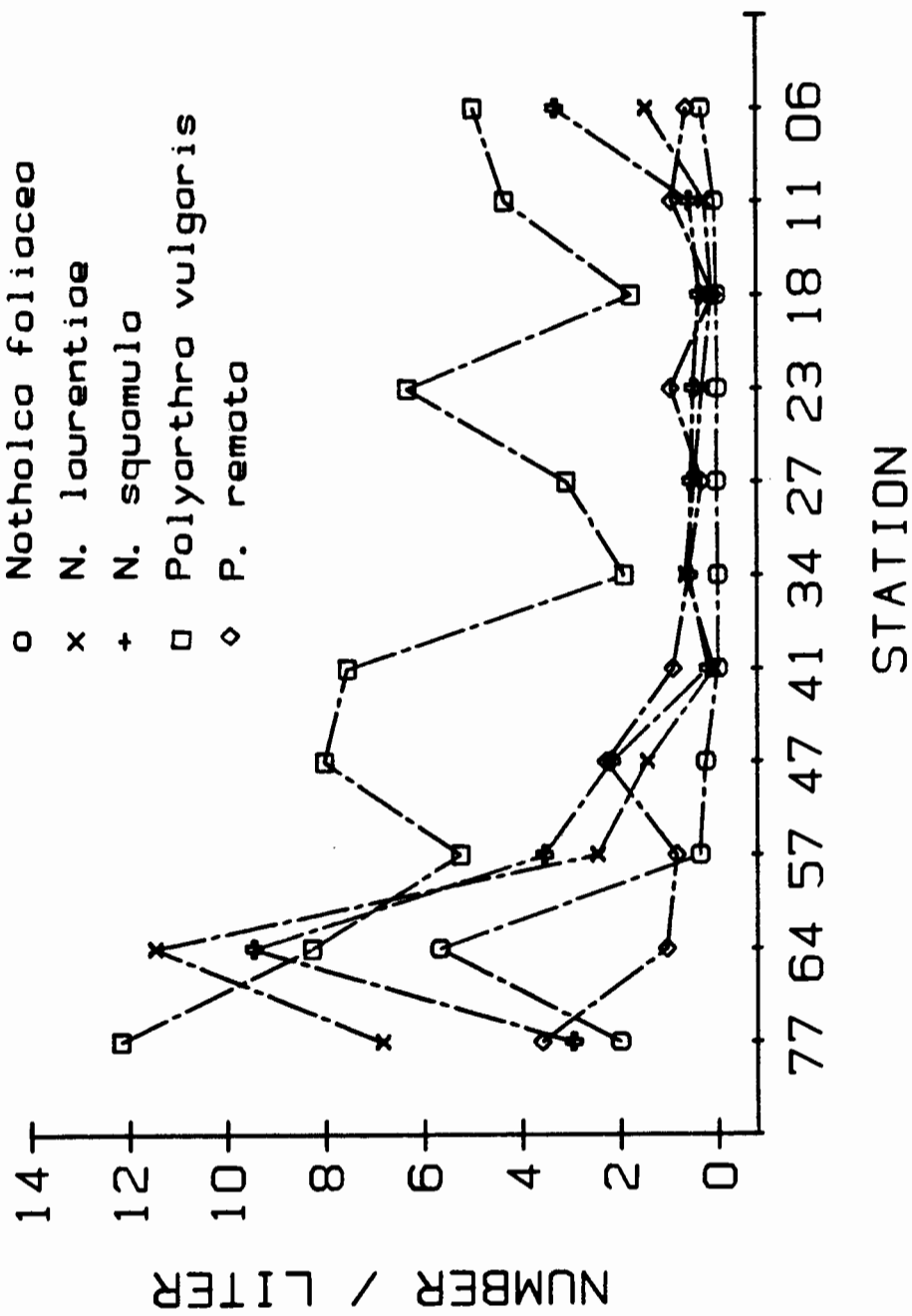


FIGURE 22. Geographical distributin of selected zooplankton in Lake Michigan, 1984.

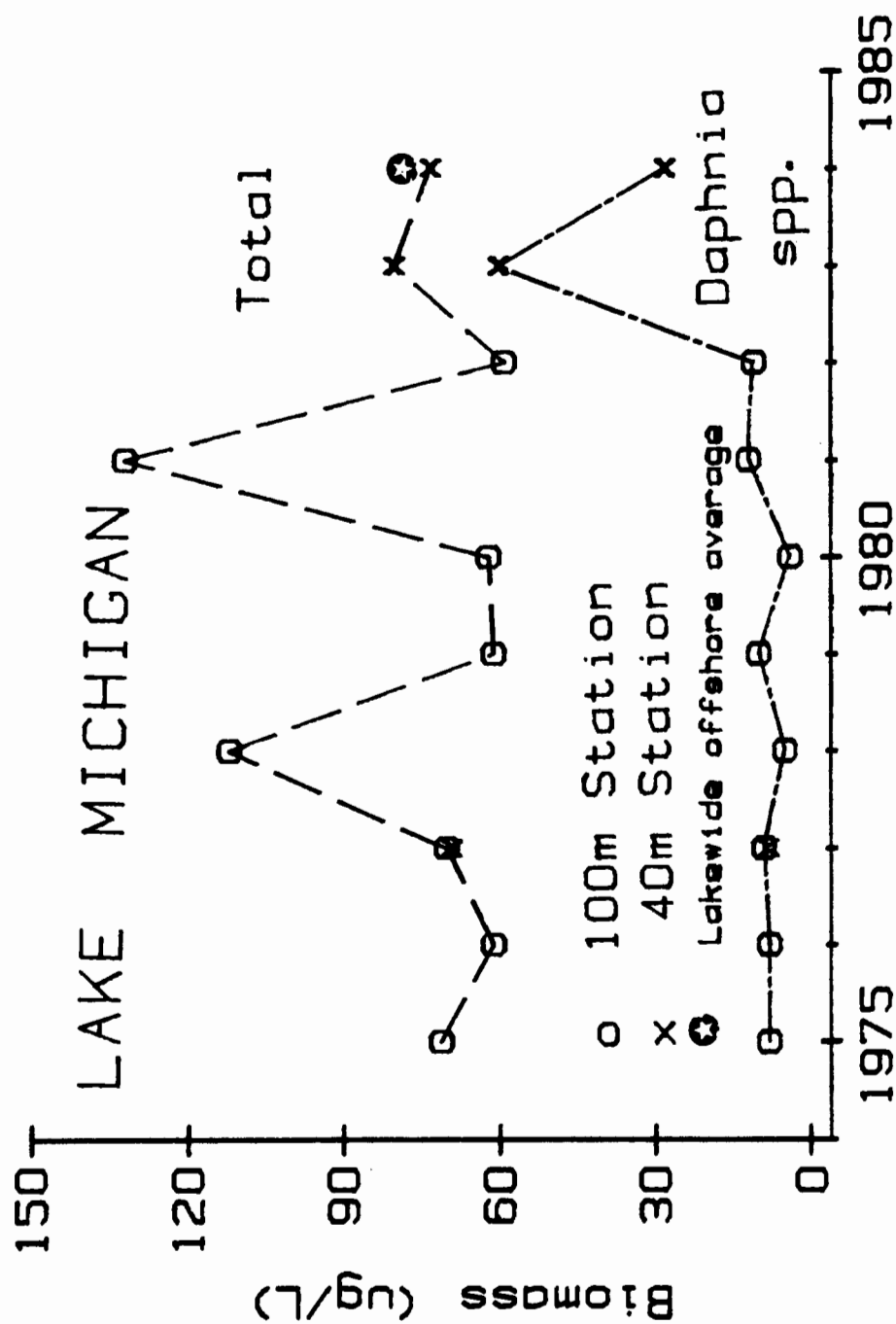


Figure 23. Historical trends in zooplankton biomass during July and August, Lake Michigan. The 1984 data point represents the mean of all offshore stations. Modified from Scavia et al. (1986).

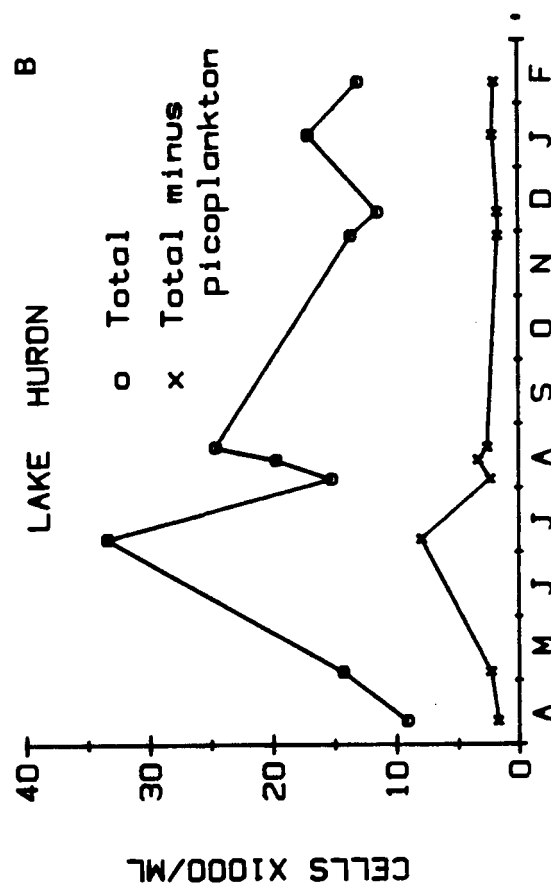
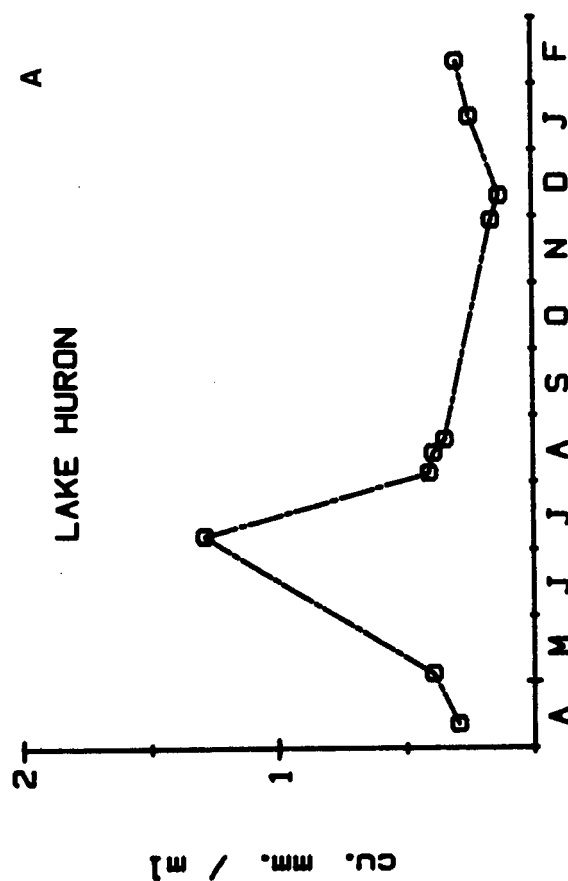


FIGURE 24. Seasonal phytoplankton biovolume (4a) and abundance (4b) trends in Lake Huron, 1984-1985.



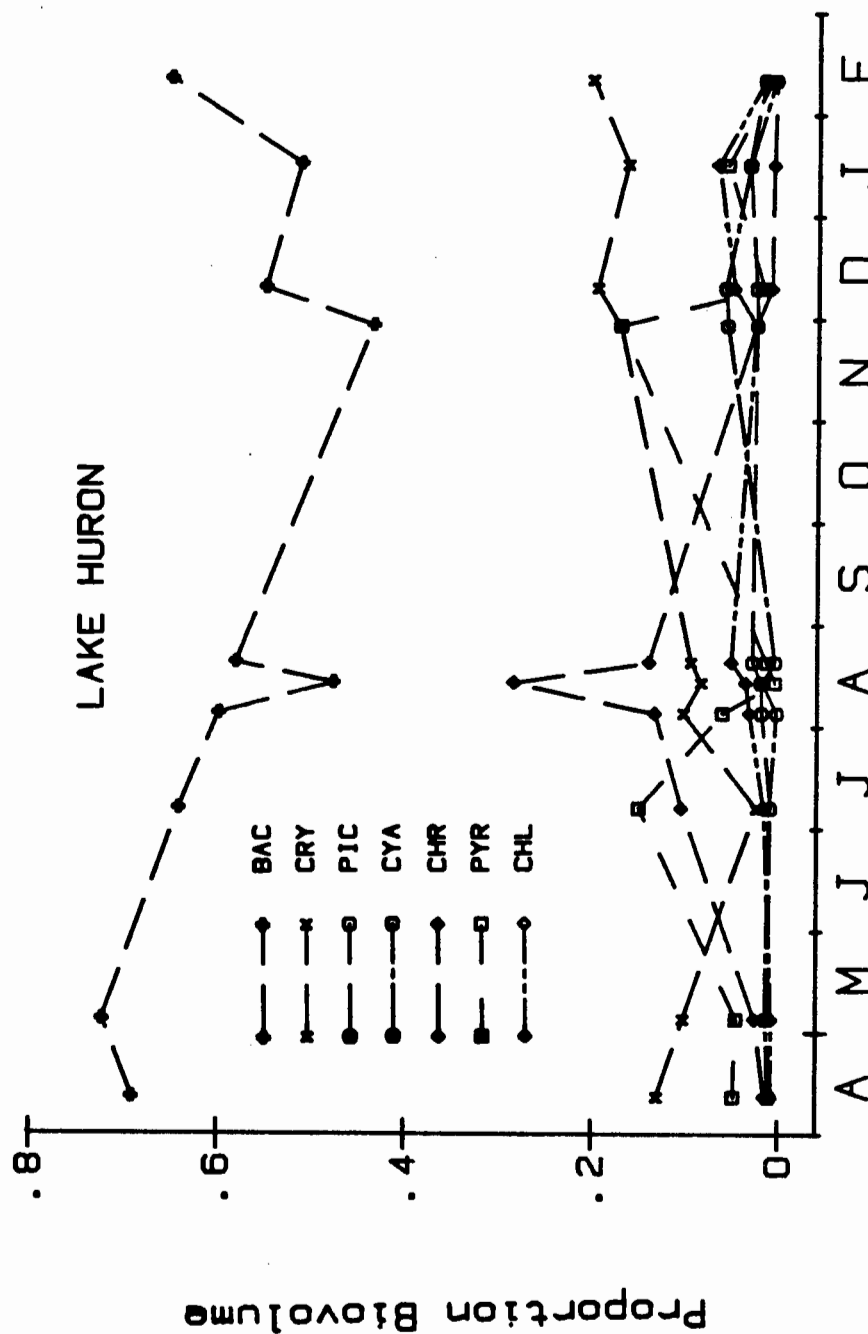


FIGURE 25. Seasonal distribution of algal (% biovolume) divisions in Lake Huron. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Cry=Cryptophyta, Cya=Cyanophyta, Pic=picoplankton, Pyr=Pyrrhophyta, 1984-85.

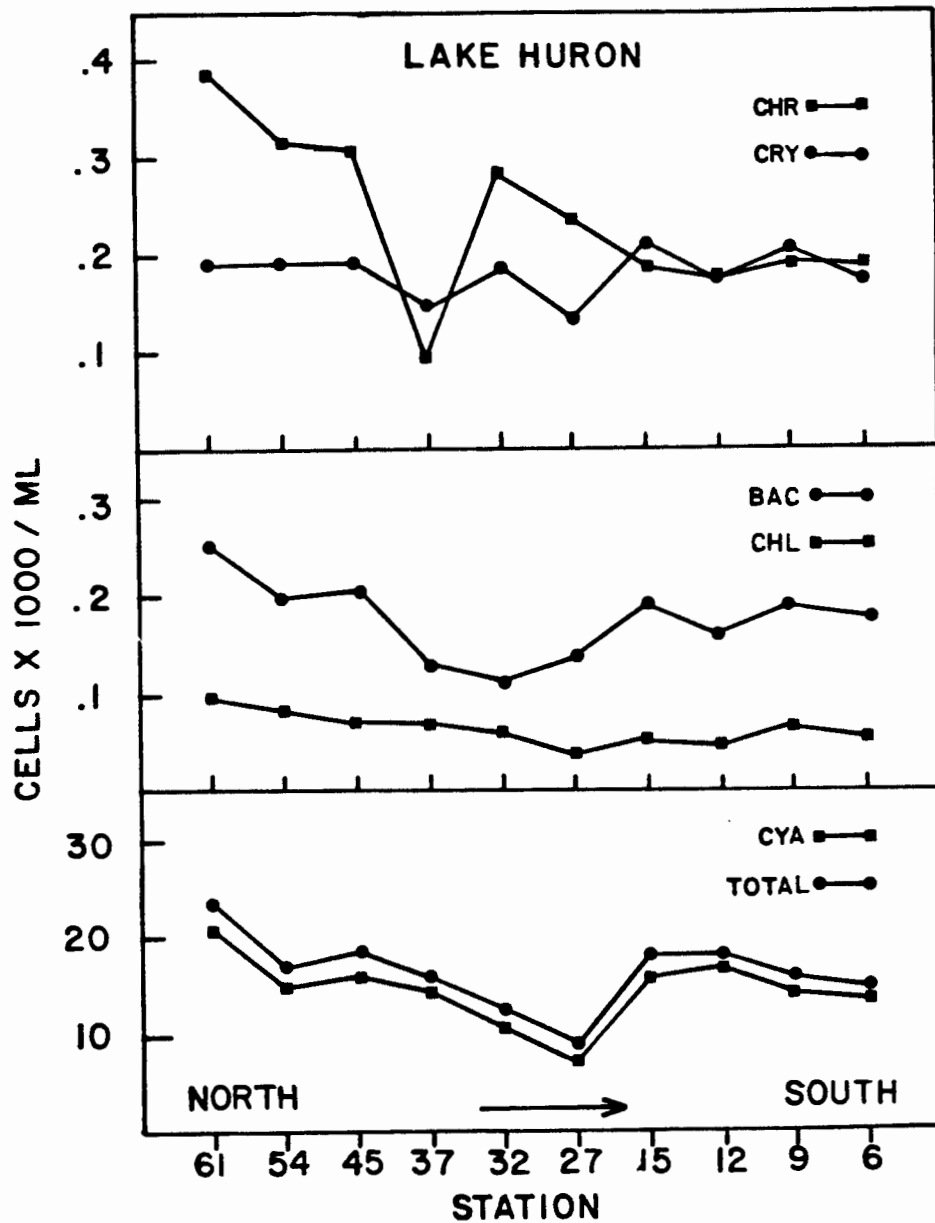


FIGURE 26. Annual geographical distribution of major algal division in Lake Huron. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Cry=Cryptophyta, Cya=Cyanophyta, Pyr=Pyrrhophyta, 1983.

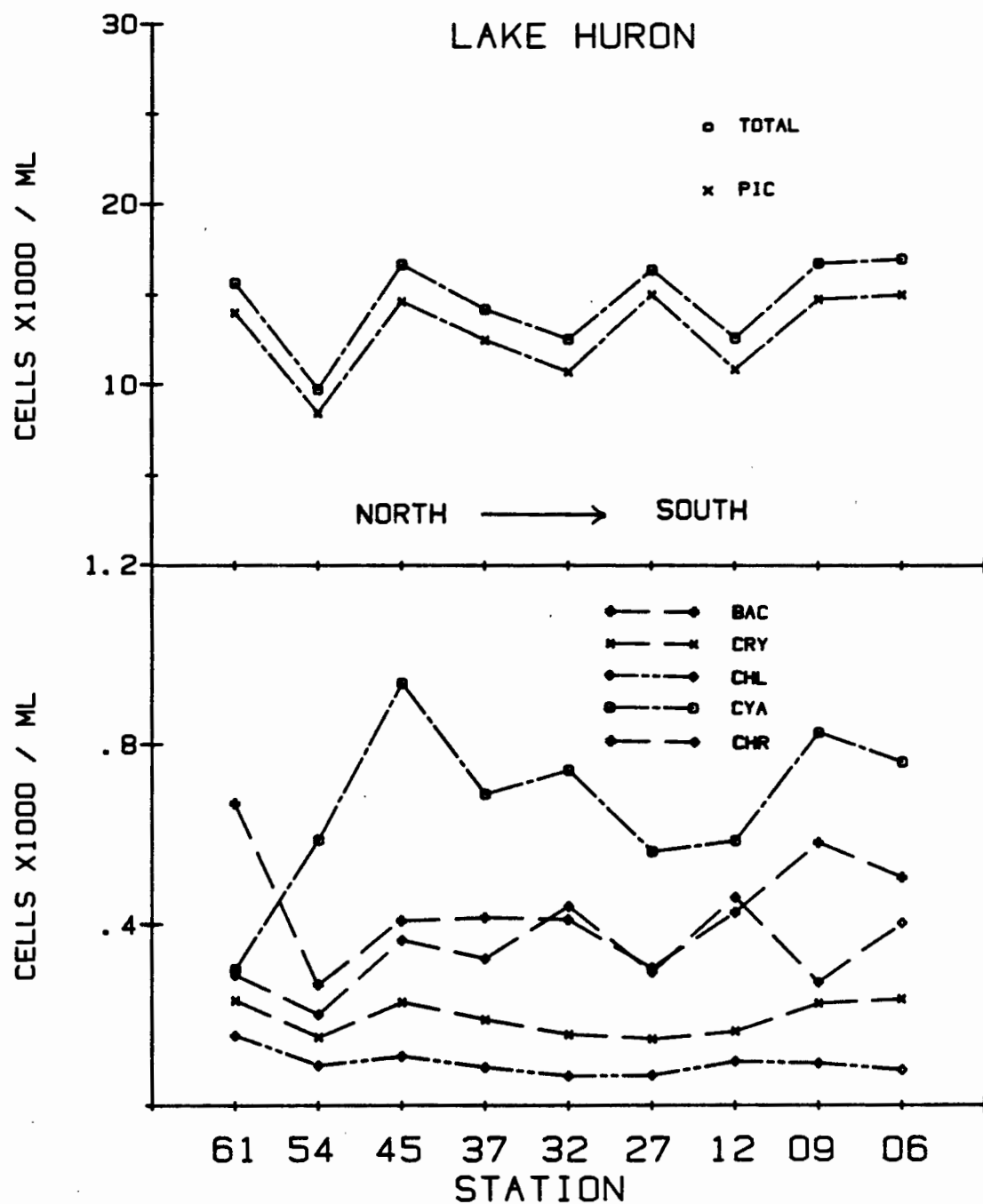


FIGURE 27. Annual geographical distribution of major algal divisions in Lake Huron. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Cry=Cryptophyta, Cya=Cyanophyta, Pic=picoplankton, Pyr=Pyrrhophyta, 1984-85.

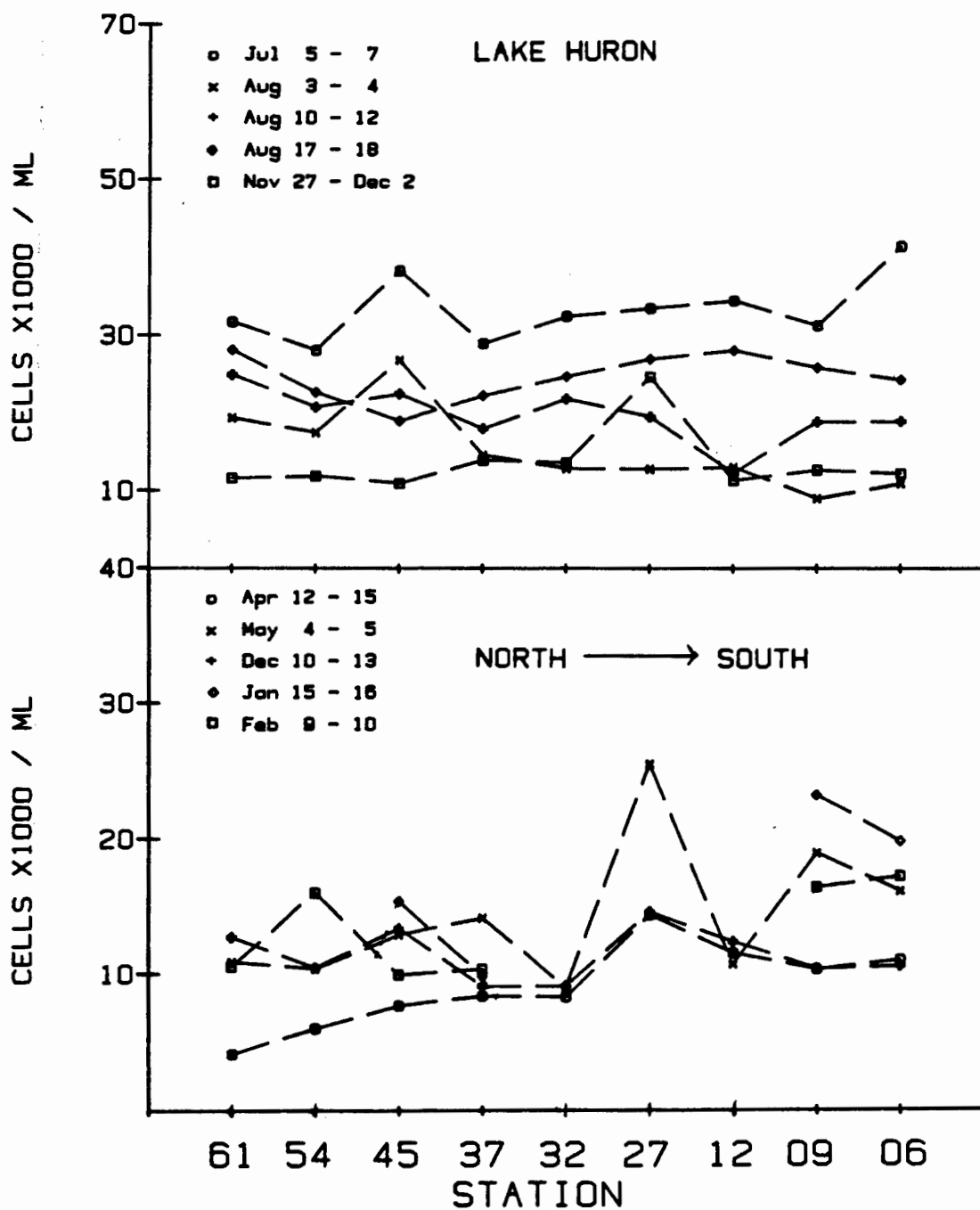


FIGURE 28. Geographical distribution of phytoplankton abundance on all cruises, Lake Huron, 1984-85.

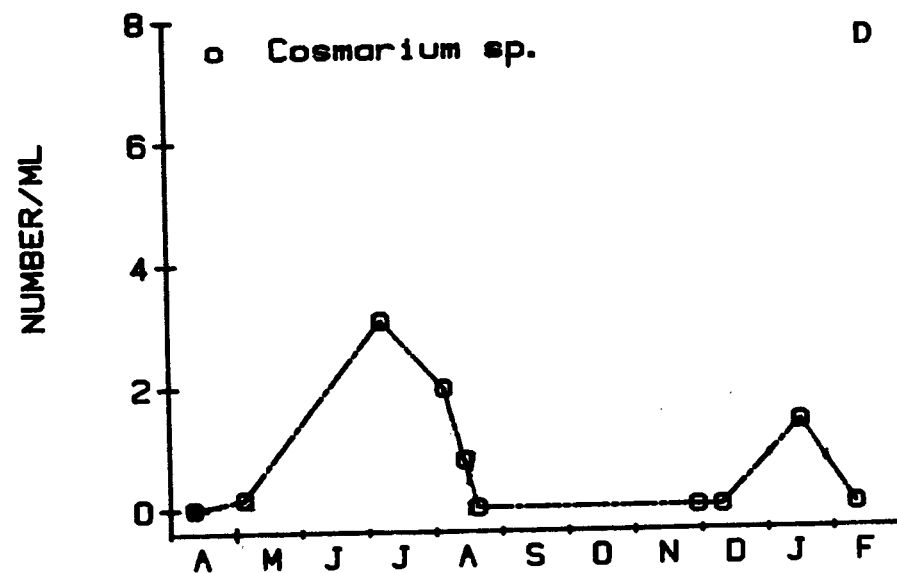
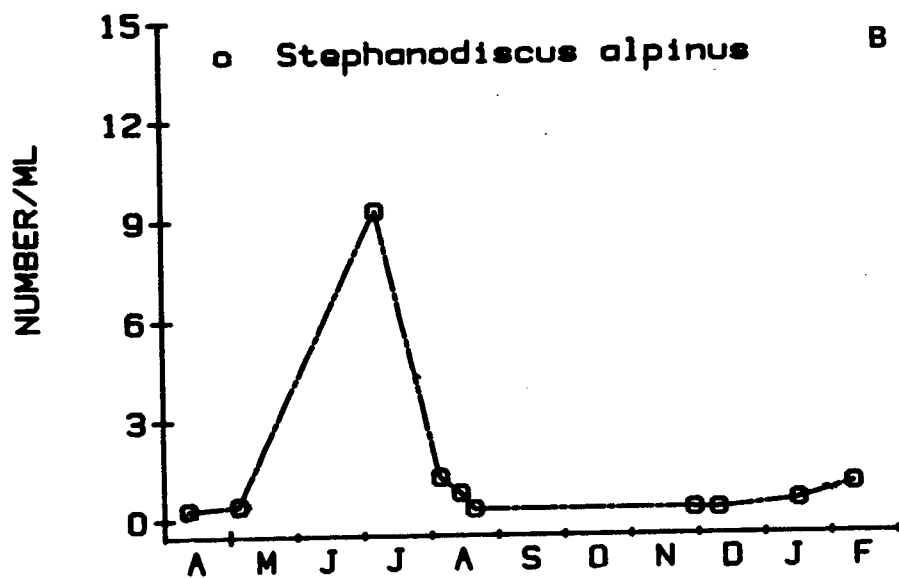
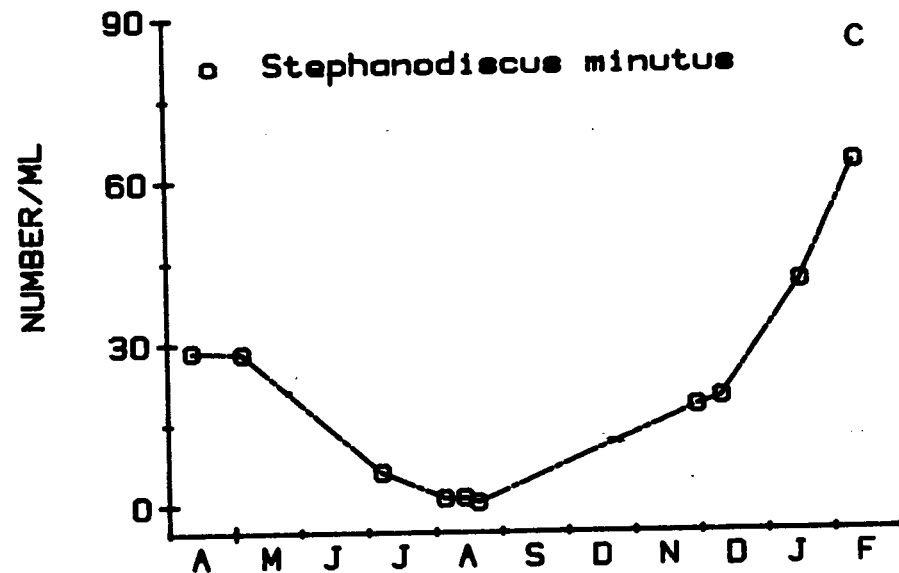
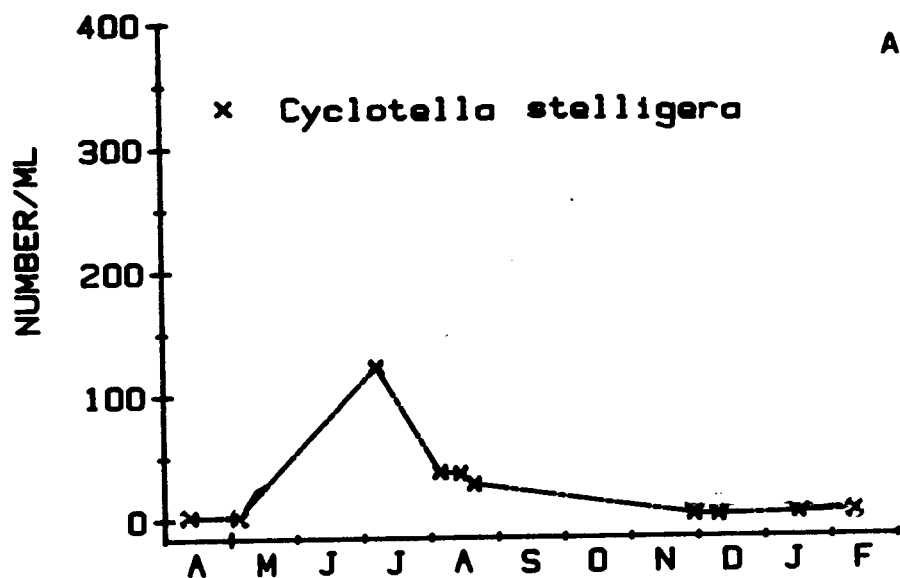


FIGURE 29. Mean seasonal distribution of a) *Cyclotella stelligera*, b) *Stephanodiscus alpinus*, c) *Stephanodiscus minutus* and d) *Cosmarium* sp., Lake Huron

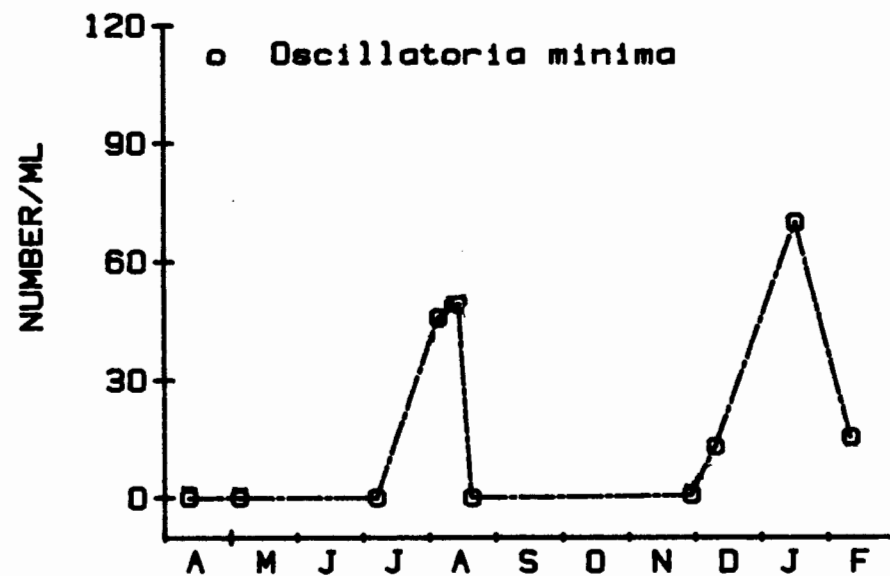


FIGURE 30. Mean seasonal distribution of *Oscillatoria minima* , Lake Huron

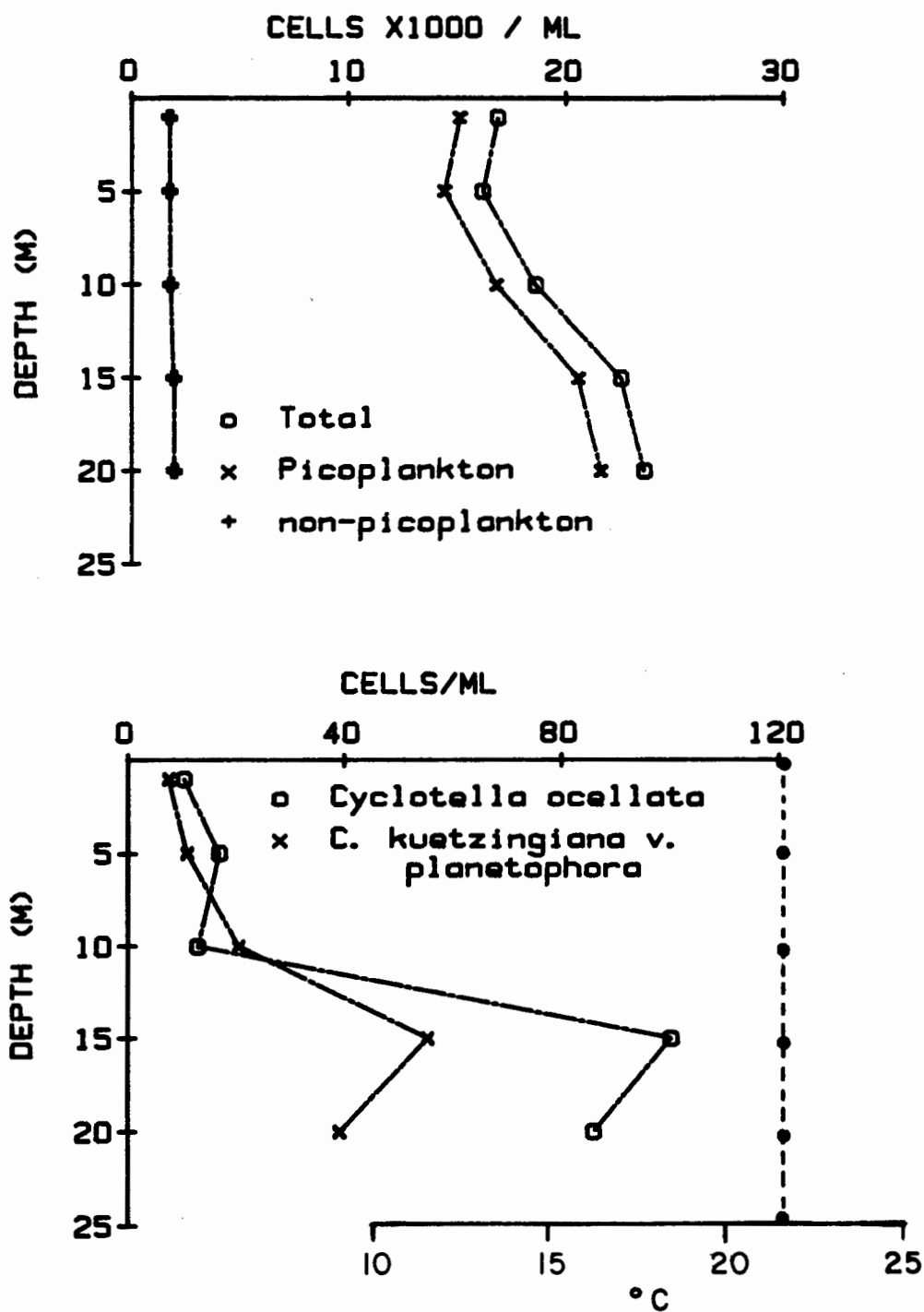
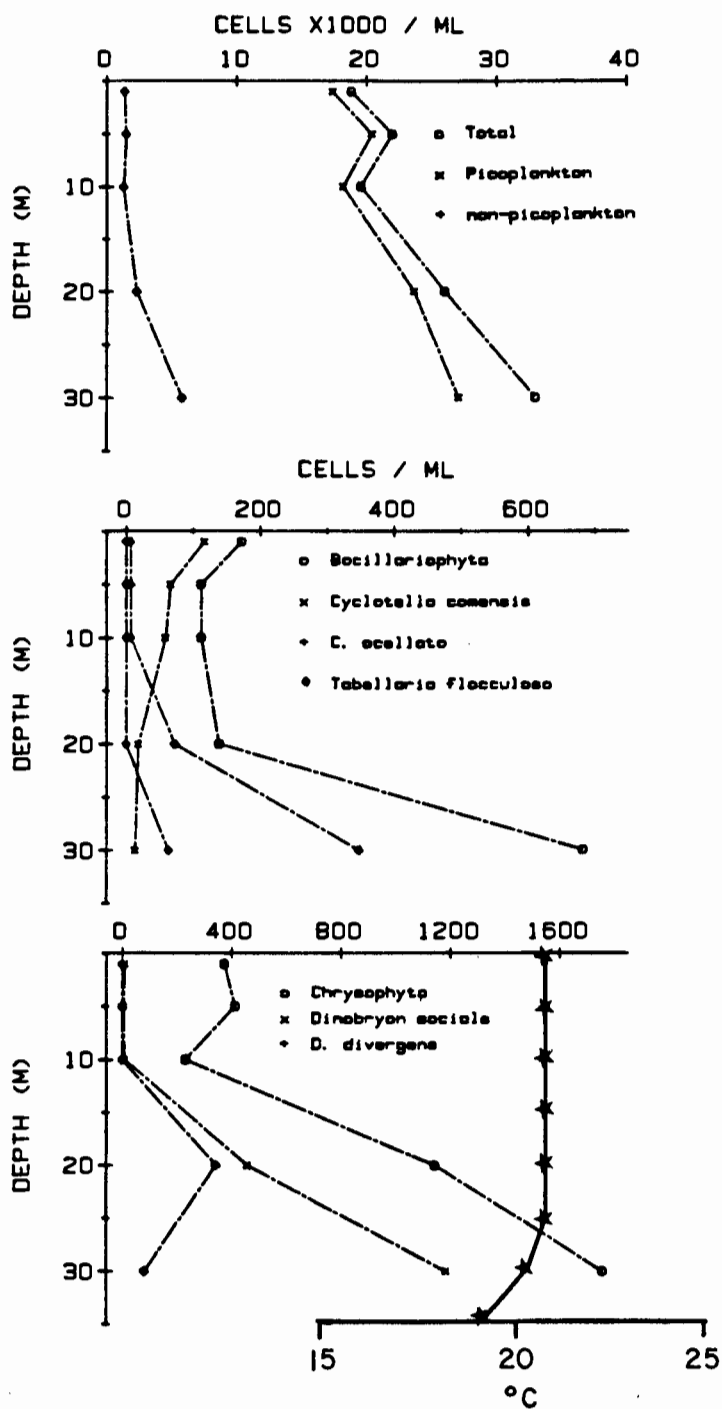


FIGURE 31. Vertical distribution of phytoplankton at Station 37, 15 August 1984, Lake Huron



**FIGURE 32.** Vertical distribution of phytoplankton at Station 15, 15 August 1984, Lake Huron



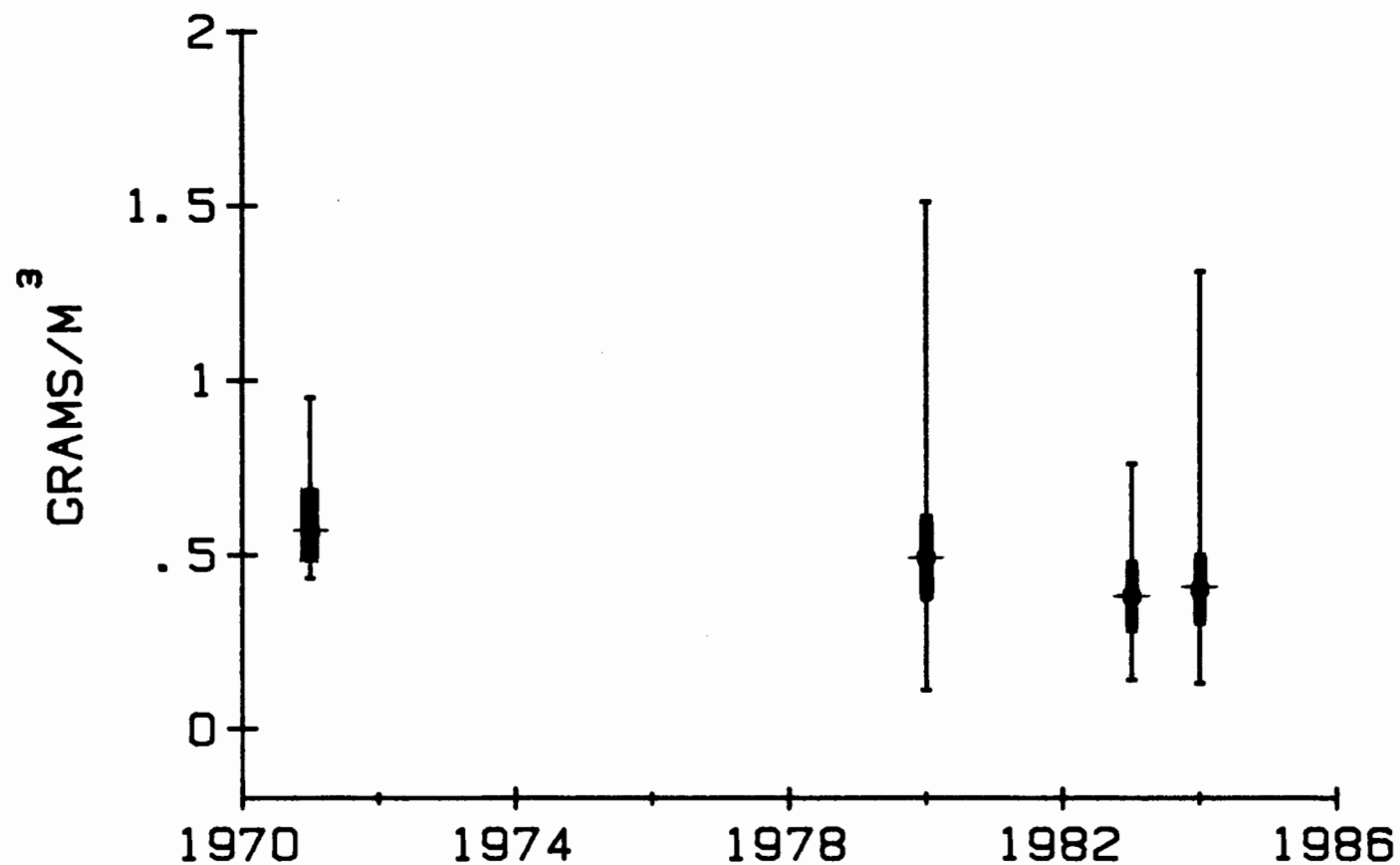


FIGURE 33. Historical offshore biomass trends in Lake Huron. Values are the mean  $\pm$  S.E. and the range. Data are from Munawar and Munawar (1979), Makarewicz (1987) and this study. 1980 offshore data are modified from a GLNPO data base.

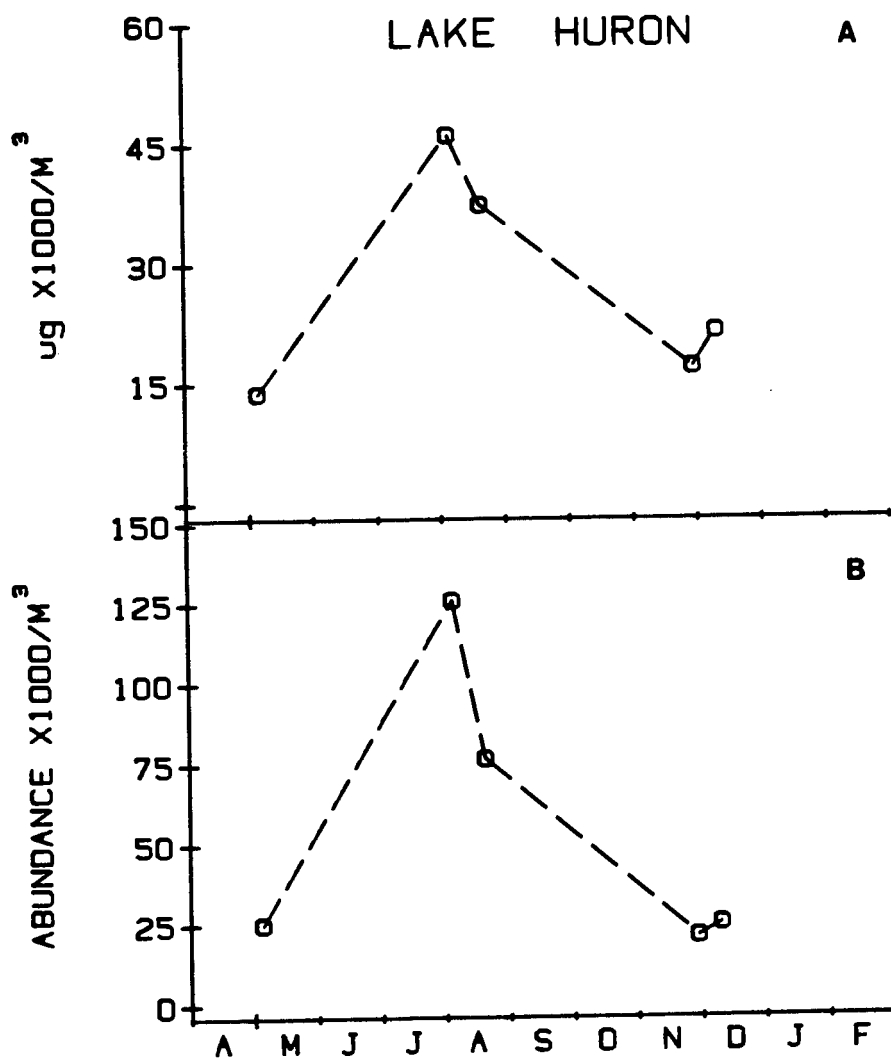
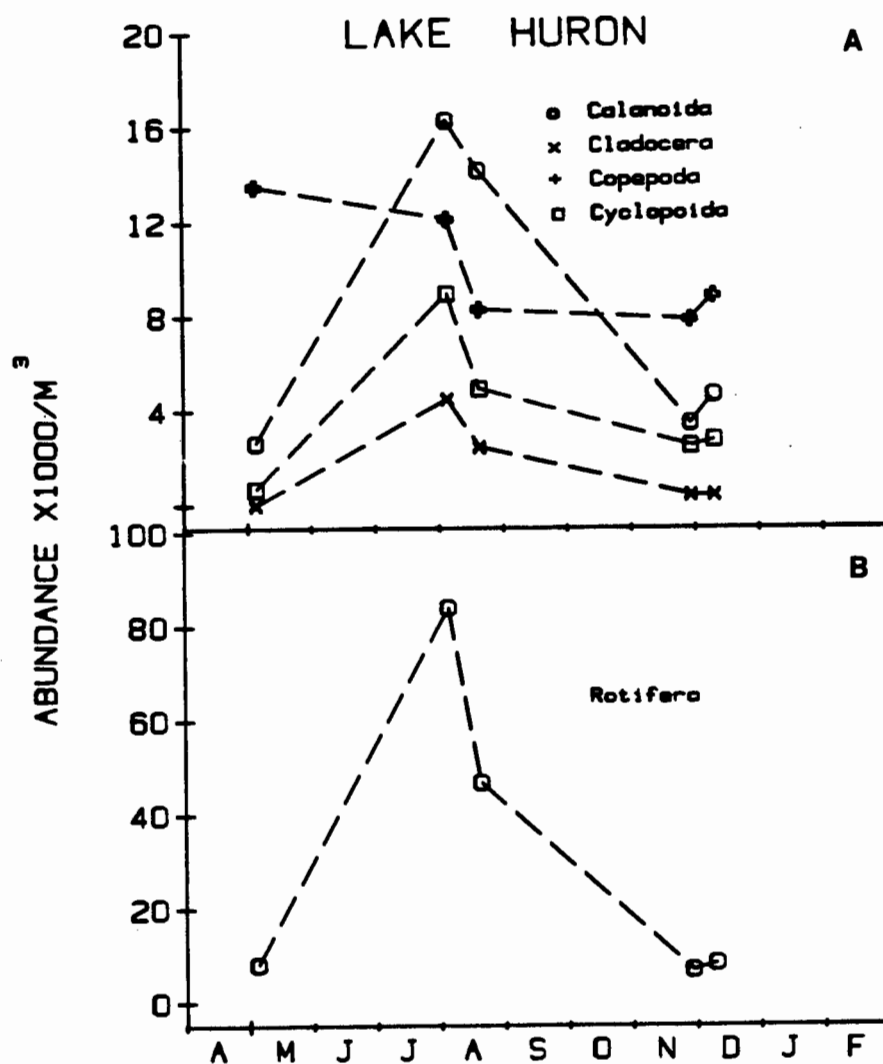
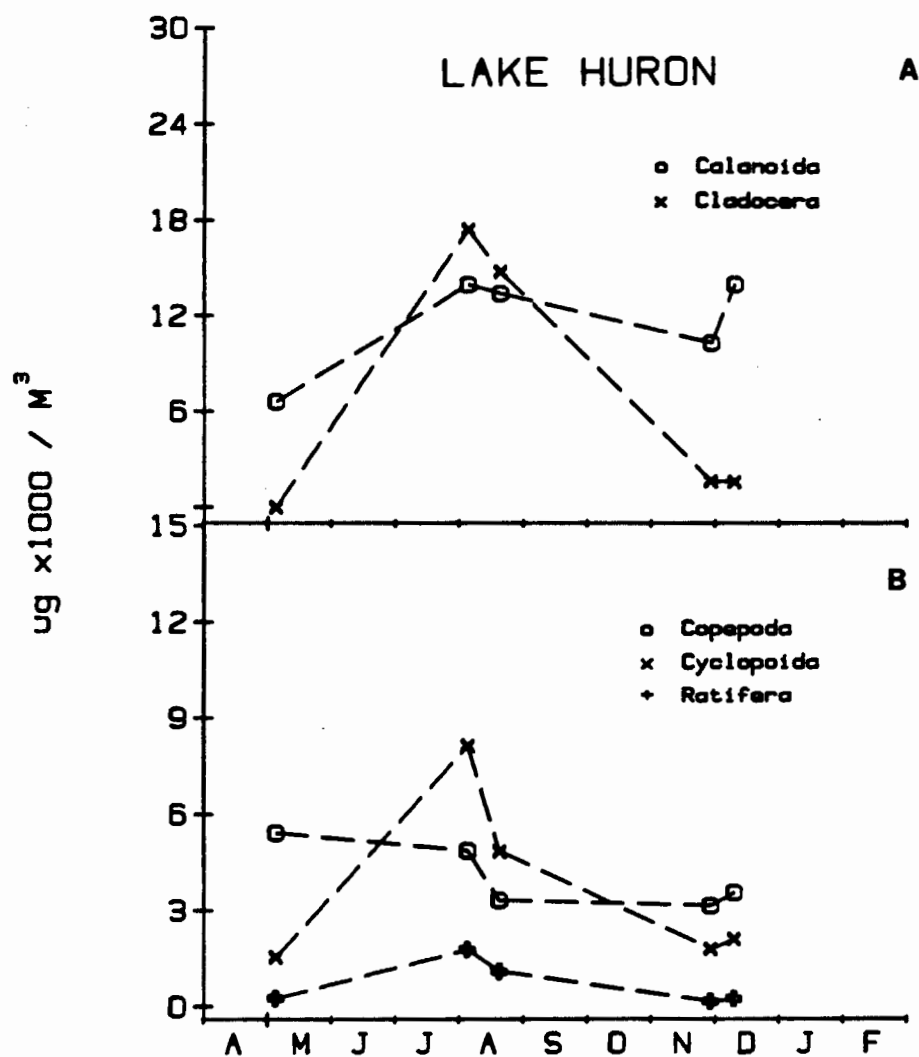


FIGURE 34. Seasonal zooplankton biomass (a) and abundance (b) in Lake Huron, 1984.



**FIGURE 35.** Seasonal fluctuation (numerical) of zooplankton groups in Lake Huron, 1984. Copepoda refer to the nauplius stage of the Copepoda.



**FIGURE 36.** Seasonal fluctuation (biomass) of zooplankton groups in Lake Huron 1984. Copepoda refers to the nauplius stage of the Copepoda.

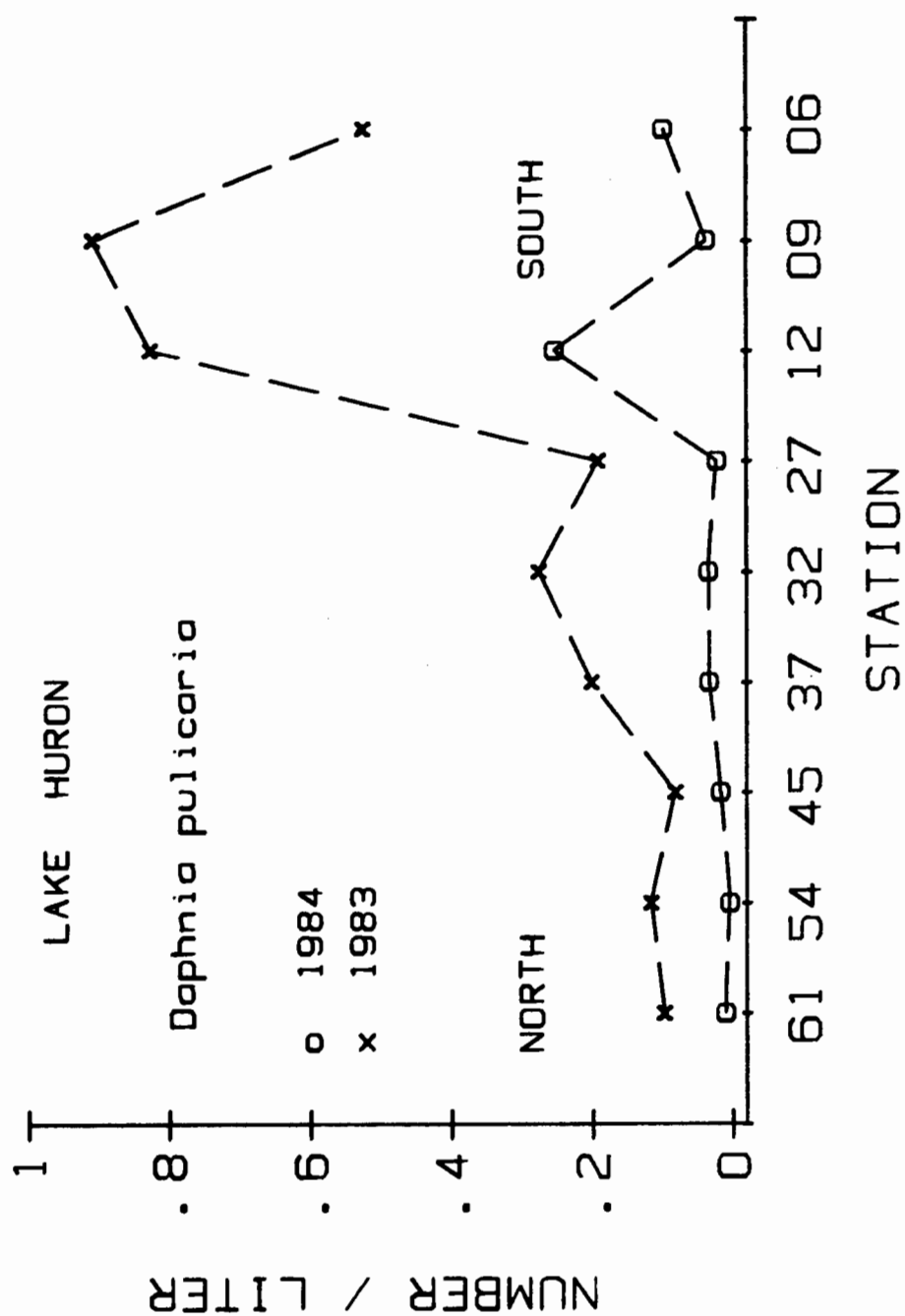
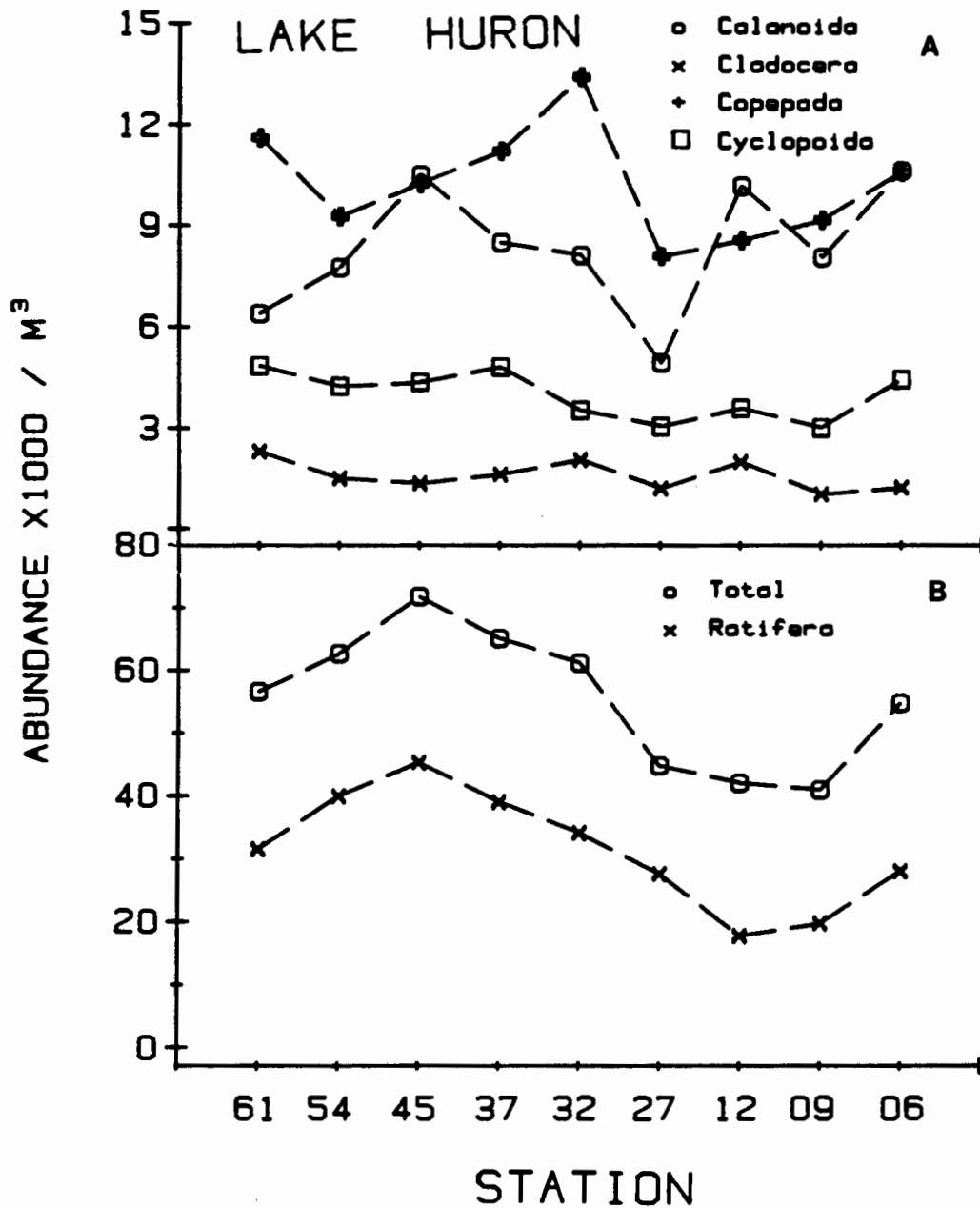
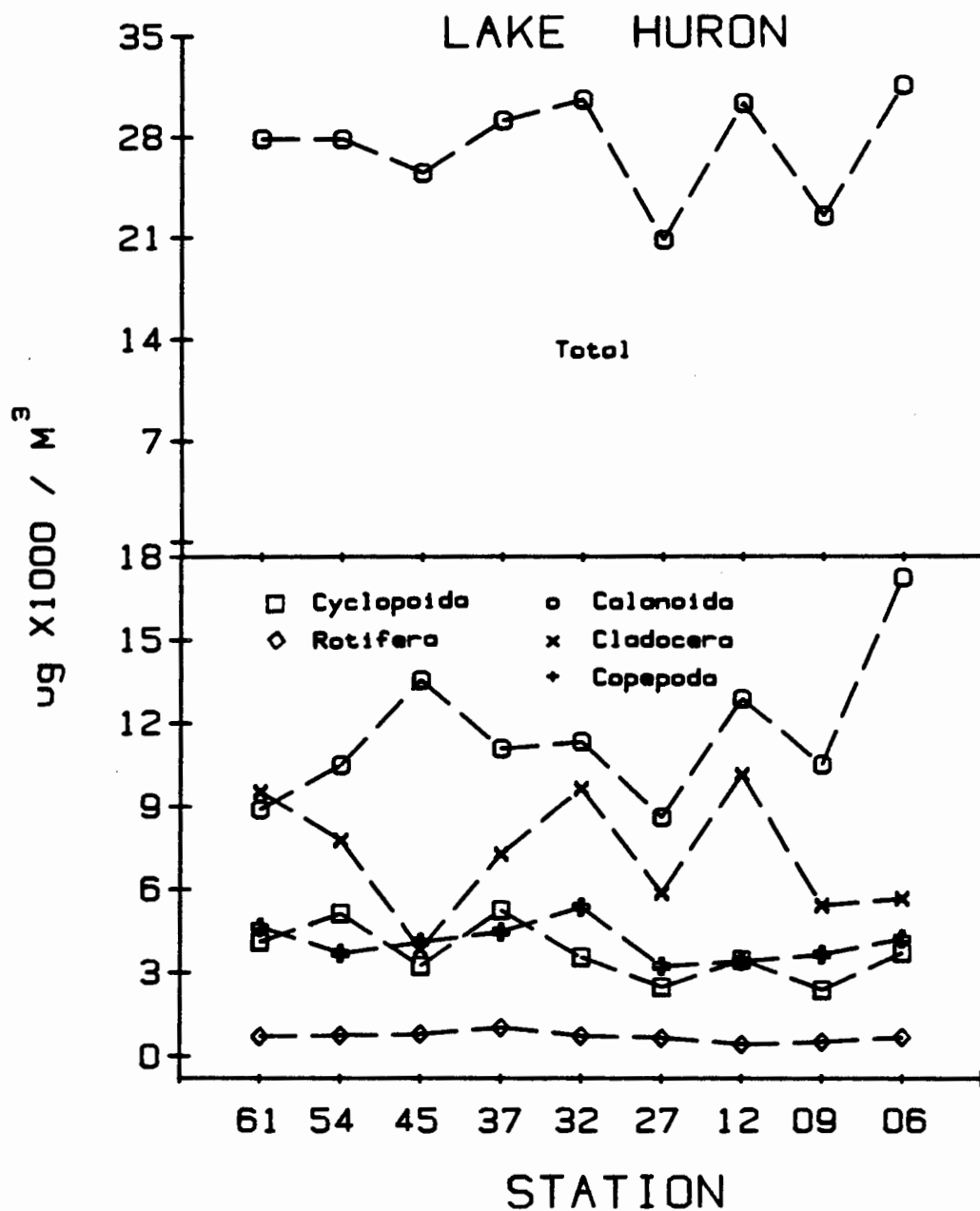


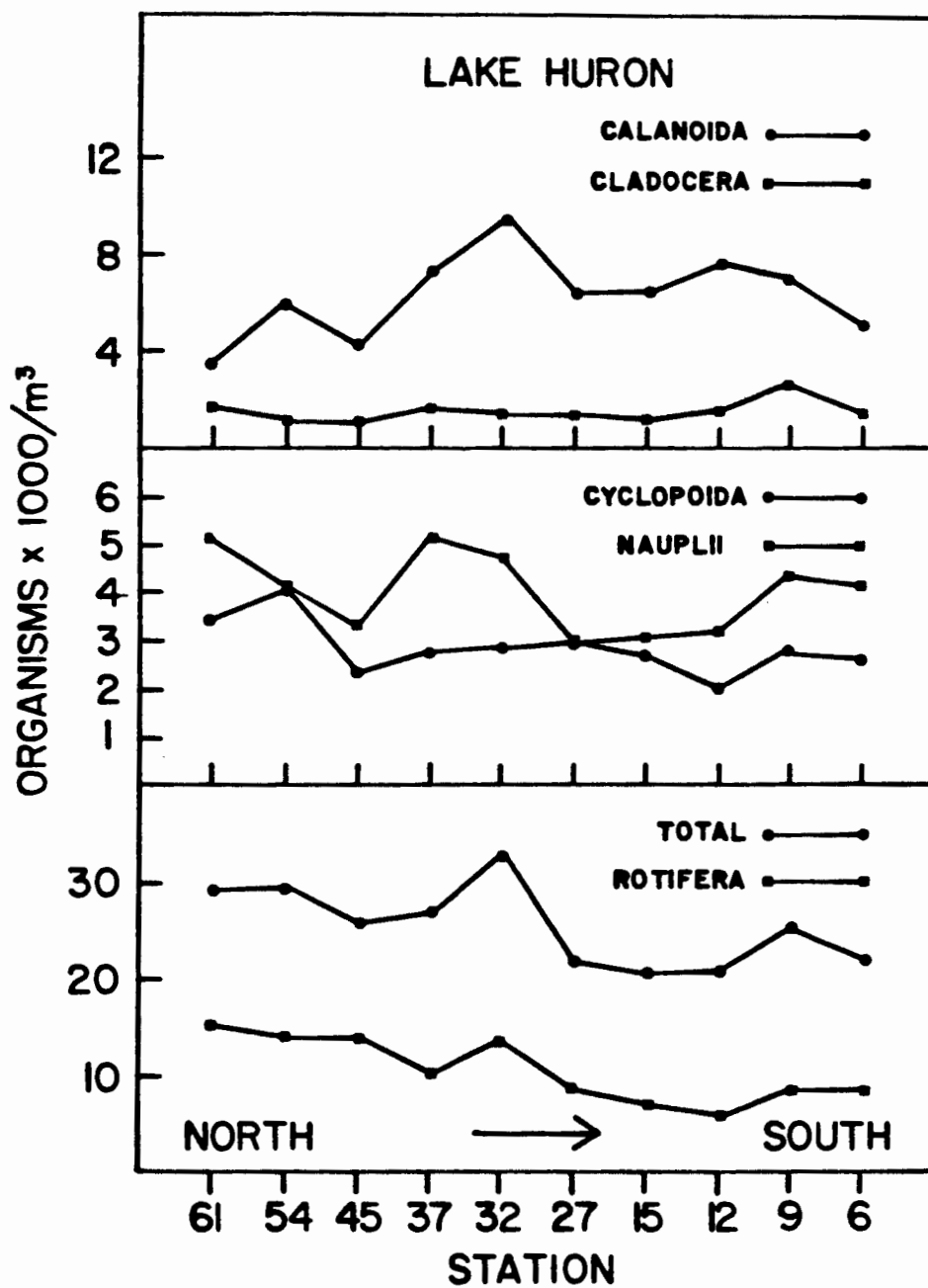
FIGURE 37. Geographical distribution of *Daphnia pulicaria* in 1983 and 1984, Lake Huron.



**FIGURE 38.** Geographical distribution (numerical) of major zooplankton groups in Lake Huron, 1984. Copepoda refers to the nauplius stage of the Copepoda.



**FIGURE 39.** Geographical distribution (biomass) of major zooplankton groups in Lake Huron, 1984. Copepoda refers to the nauplius stage of the Copepoda.



**FIGURE 40.** Geographical distribution of major zooplankton groups in Lake Huron, 1983.



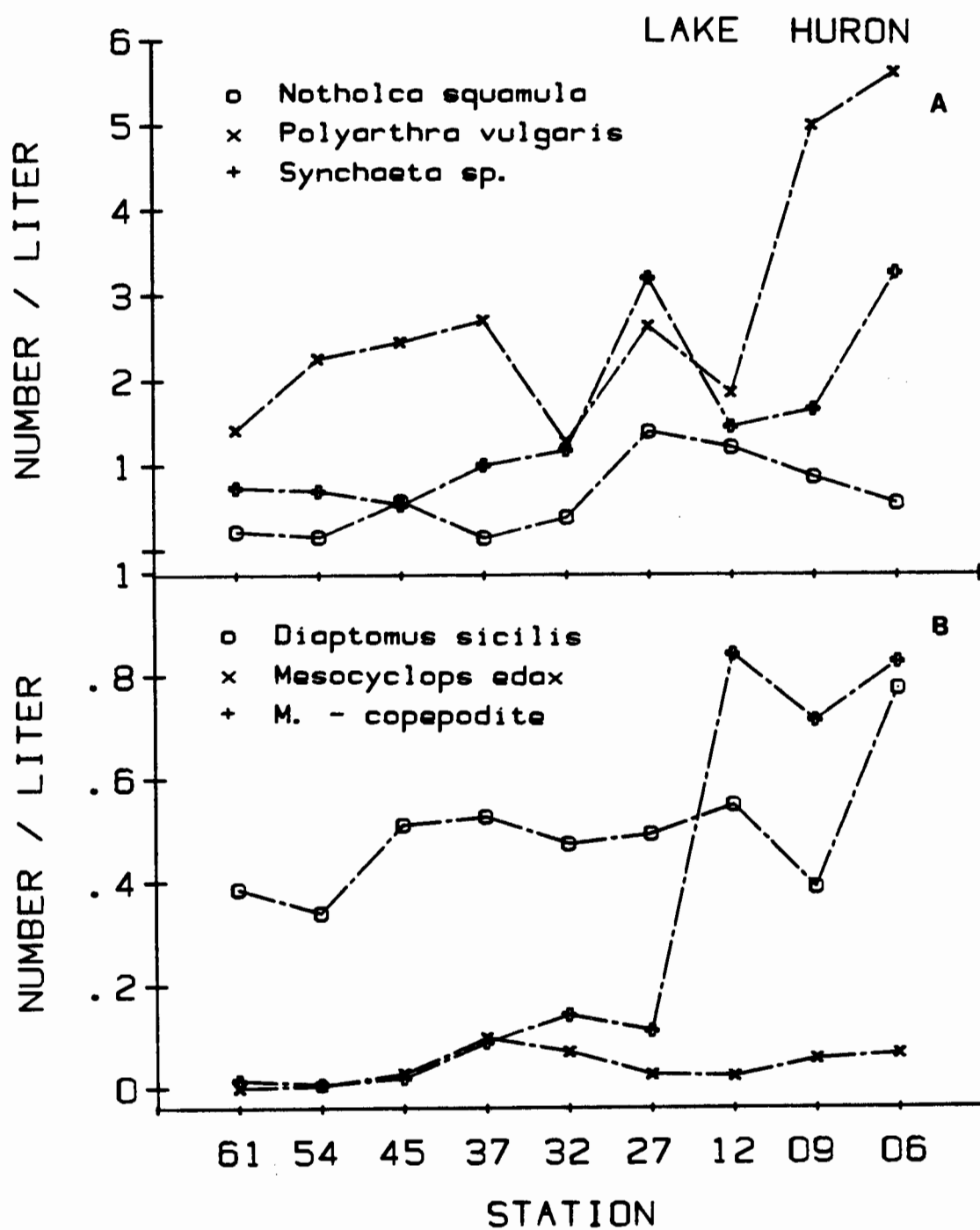
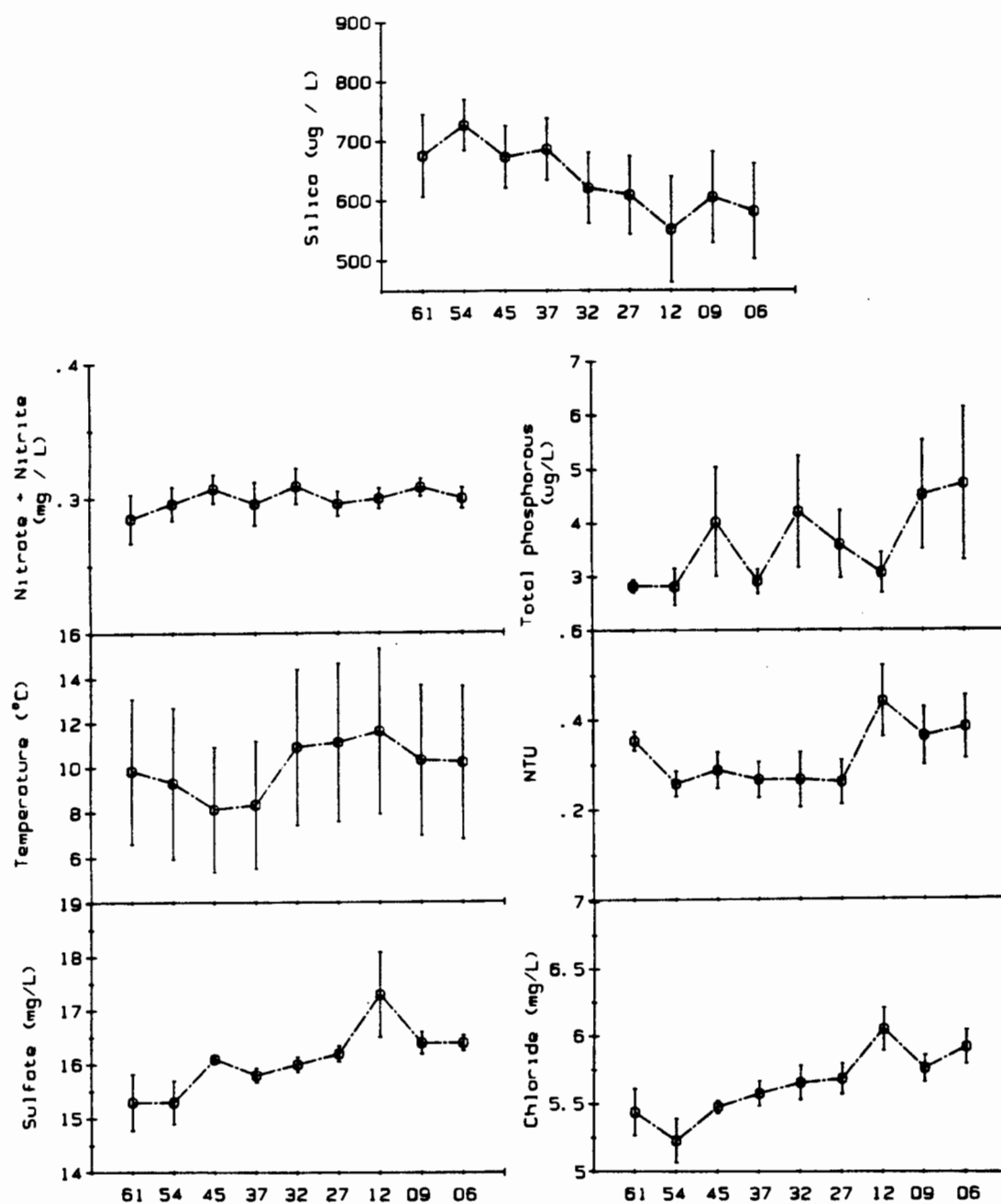


FIGURE 41. Geographical distribution of selected Rotifera (a) and Copepoda (b) in Lake Huron, 1984.



**Figure 42.** Water chemistry along the north-south axis of Lake Huron, 1984. Values are the station mean  $\pm$  S.E.

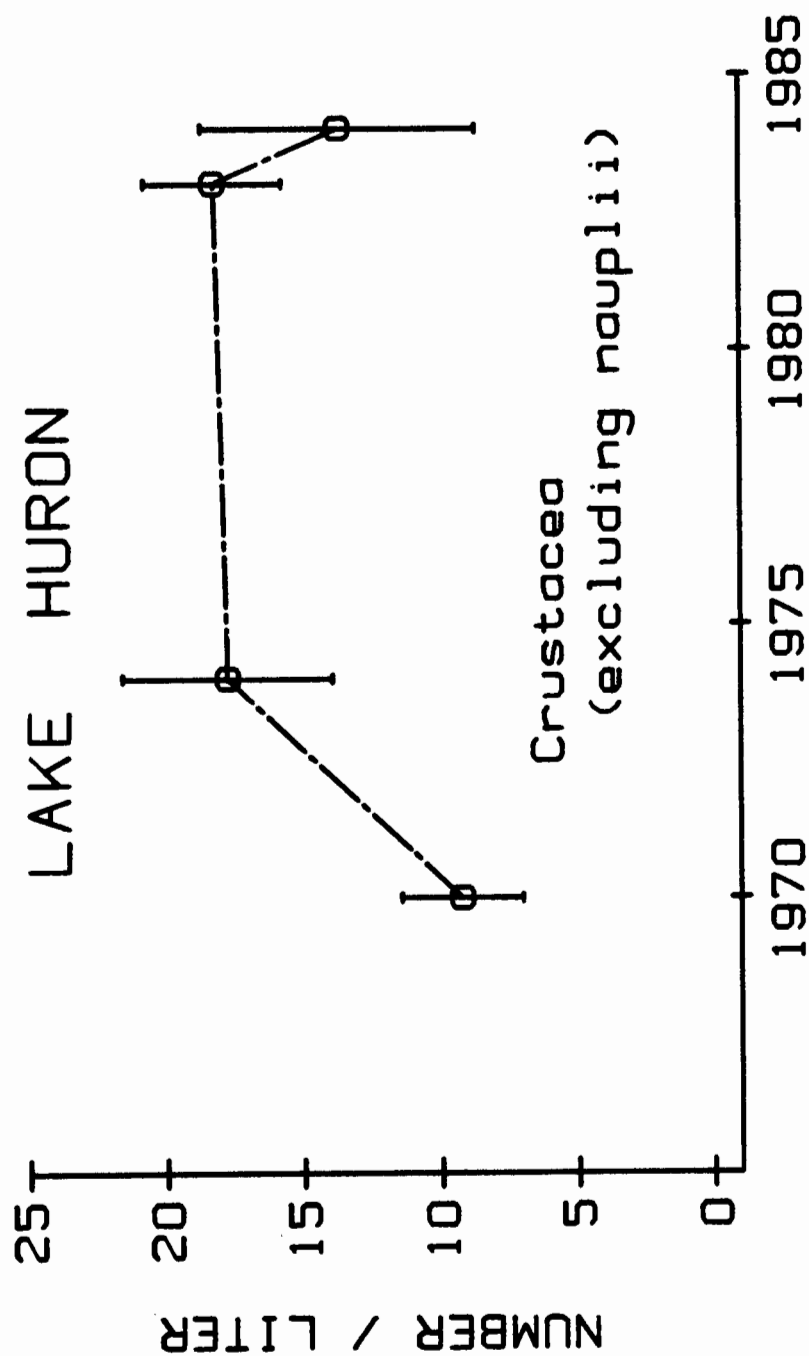


Figure 43. Crustacean abundance (excluding nauplii) of Lake Huron, 1970-1984. 1970:Watson and Carpenter (1974). 1974:McNaught (1980), 1983:Makarewicz (1987). 1974 data represent offshore sites only (Areas 9 and 10). Values are the mean  $\pm$  S.E.

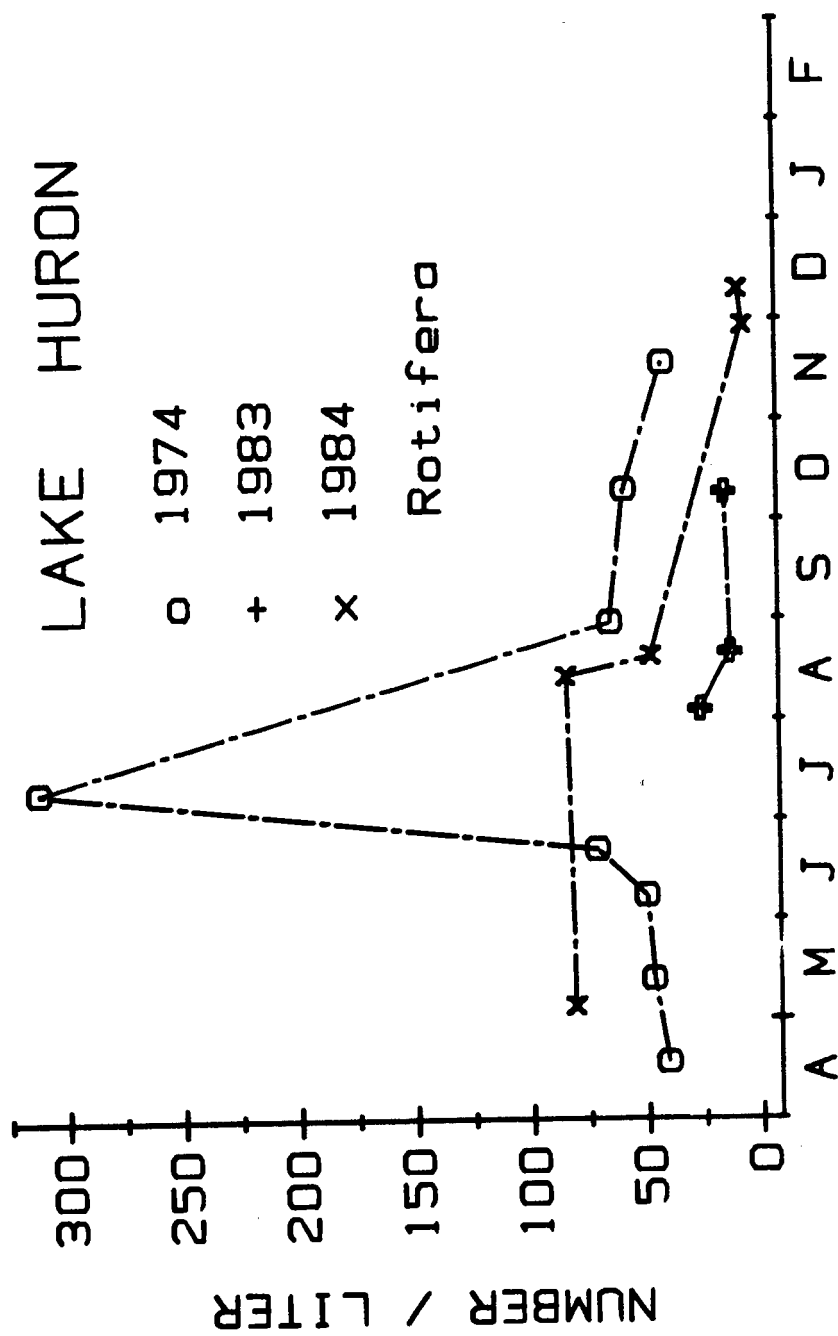


Figure 44. Abundance of Rotifera in Lake Huron in 1974, 1983 and 1984. 1974 data are from offshore stations only (Stemberger et al. 1979).

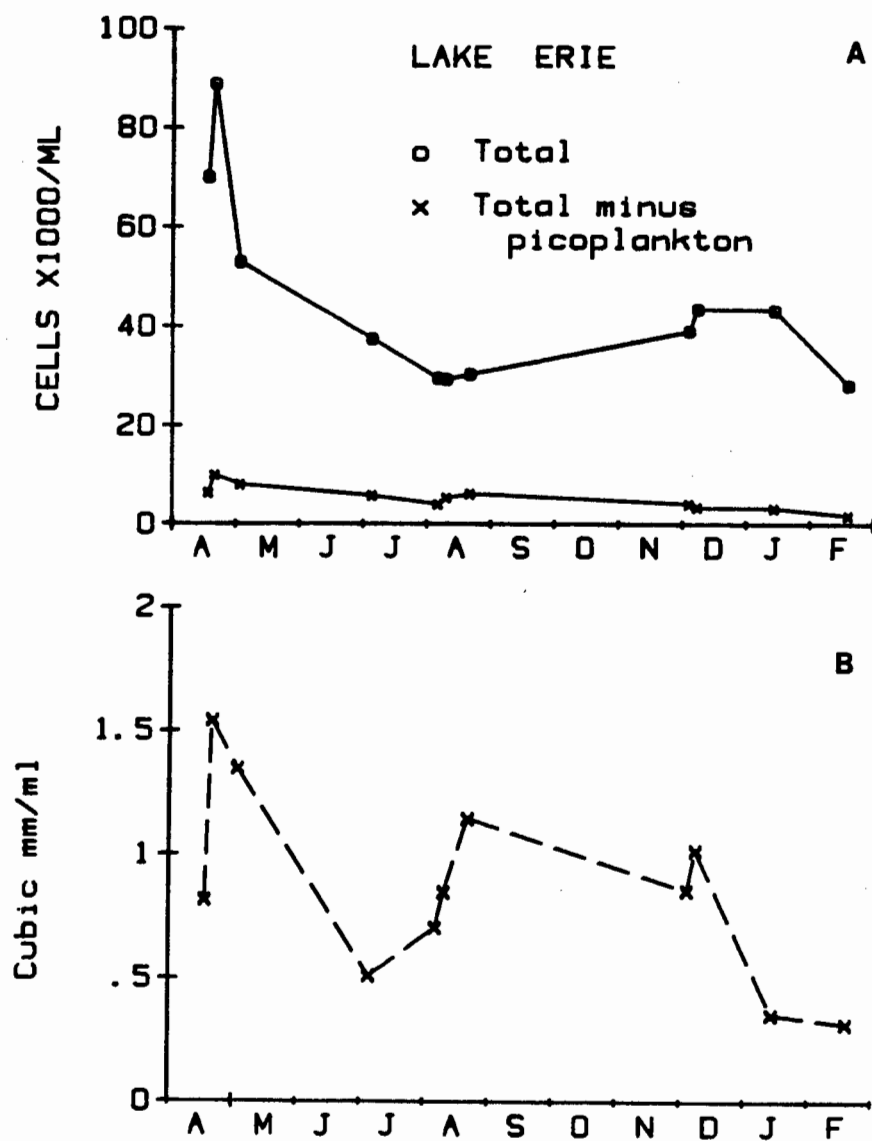


FIGURE 45. Seasonal phytoplankton abundance (a) and biovolume (b) trends in Lake Erie, 1984-85.

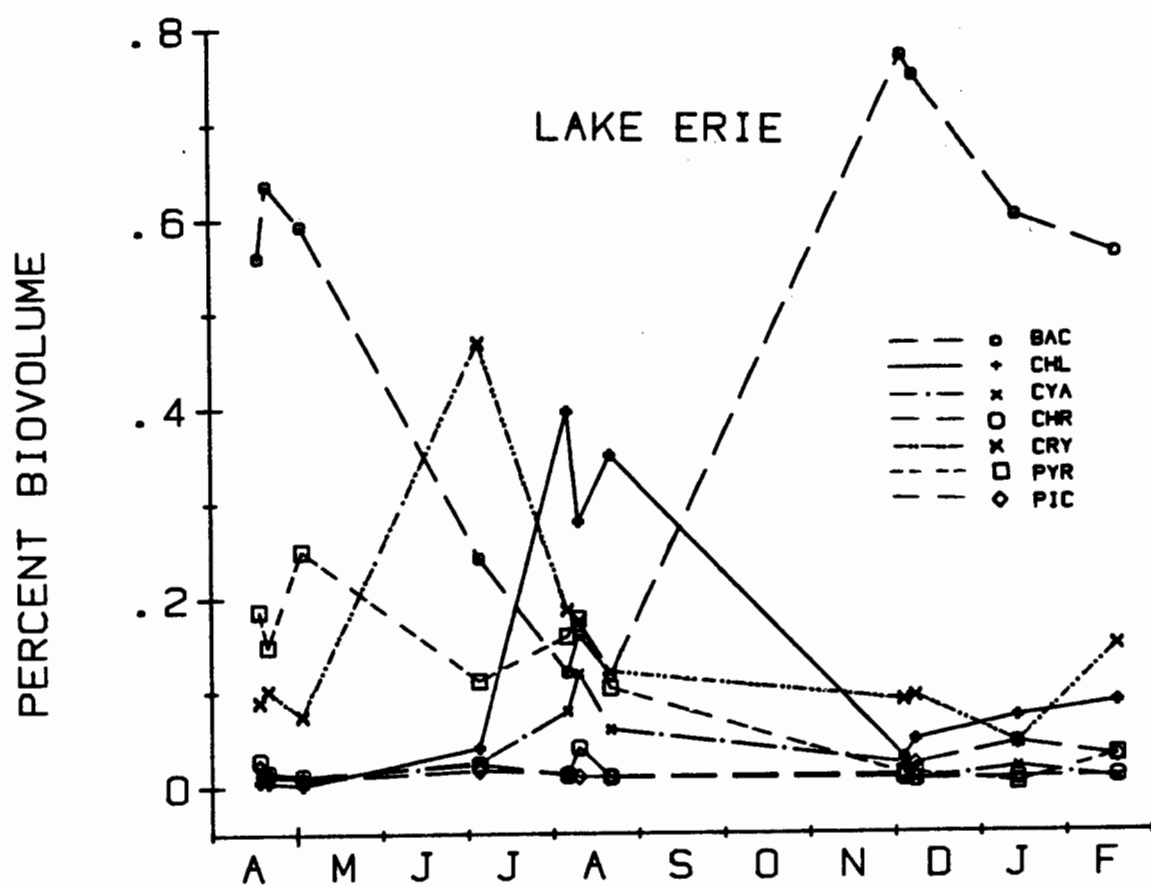


FIGURE 46. Seasonal distribution of algal divisions in Lake Erie. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Cry=Cryptophyta, Cya=Cyanophyta, Pic=Picoplankton, Pyr=Pyrrhophyta, 1984-85.

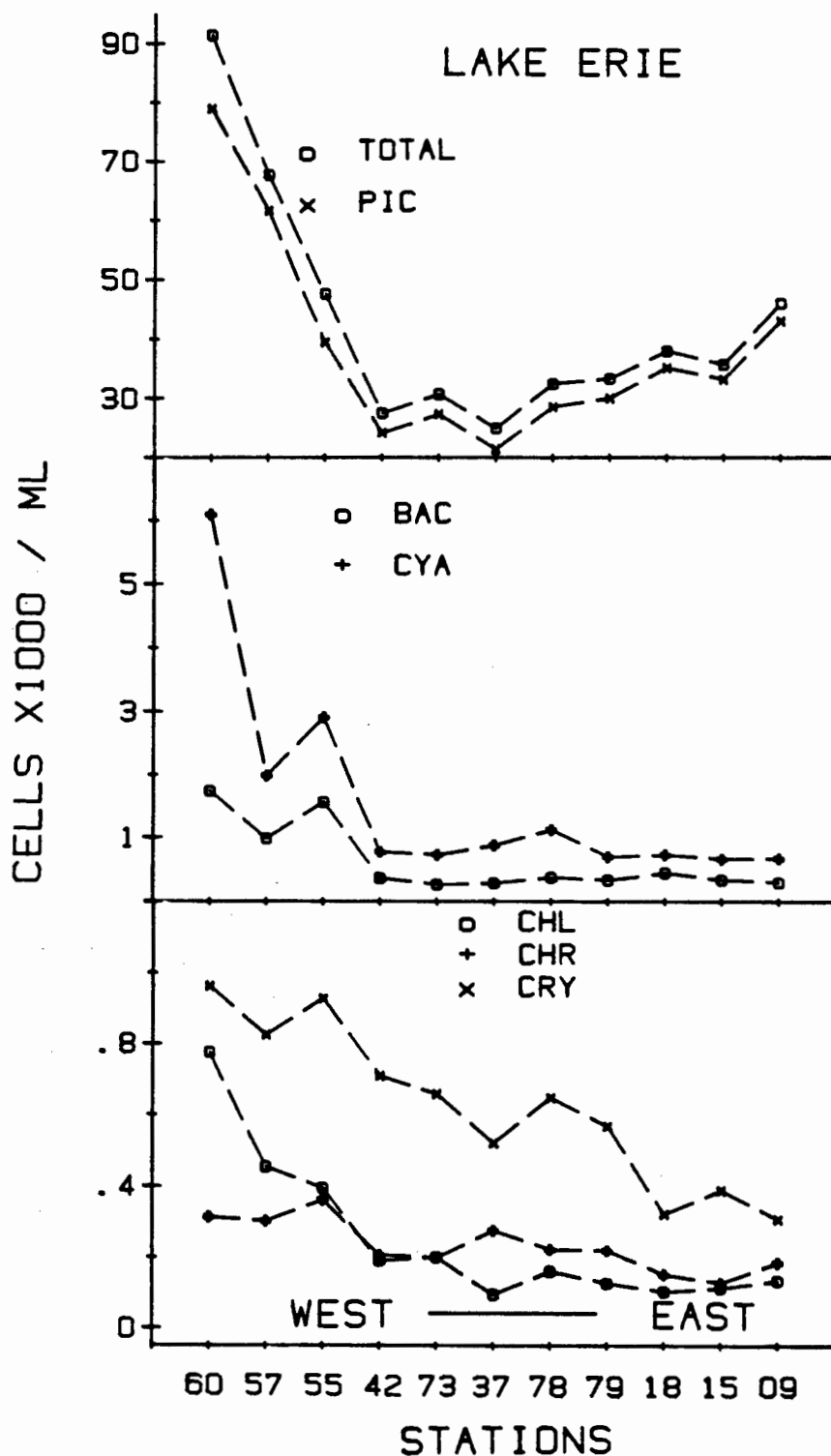


FIGURE 47. Annual geographical distribution of major algal divisions in Lake Erie. Bac=Bacillariophyta, Chl=Chlorophyta, Chr=Chrysophyta, Cry=Cryptophyta, Cya=Cyanophyta, Pic=Picoplankton, 1984-85.

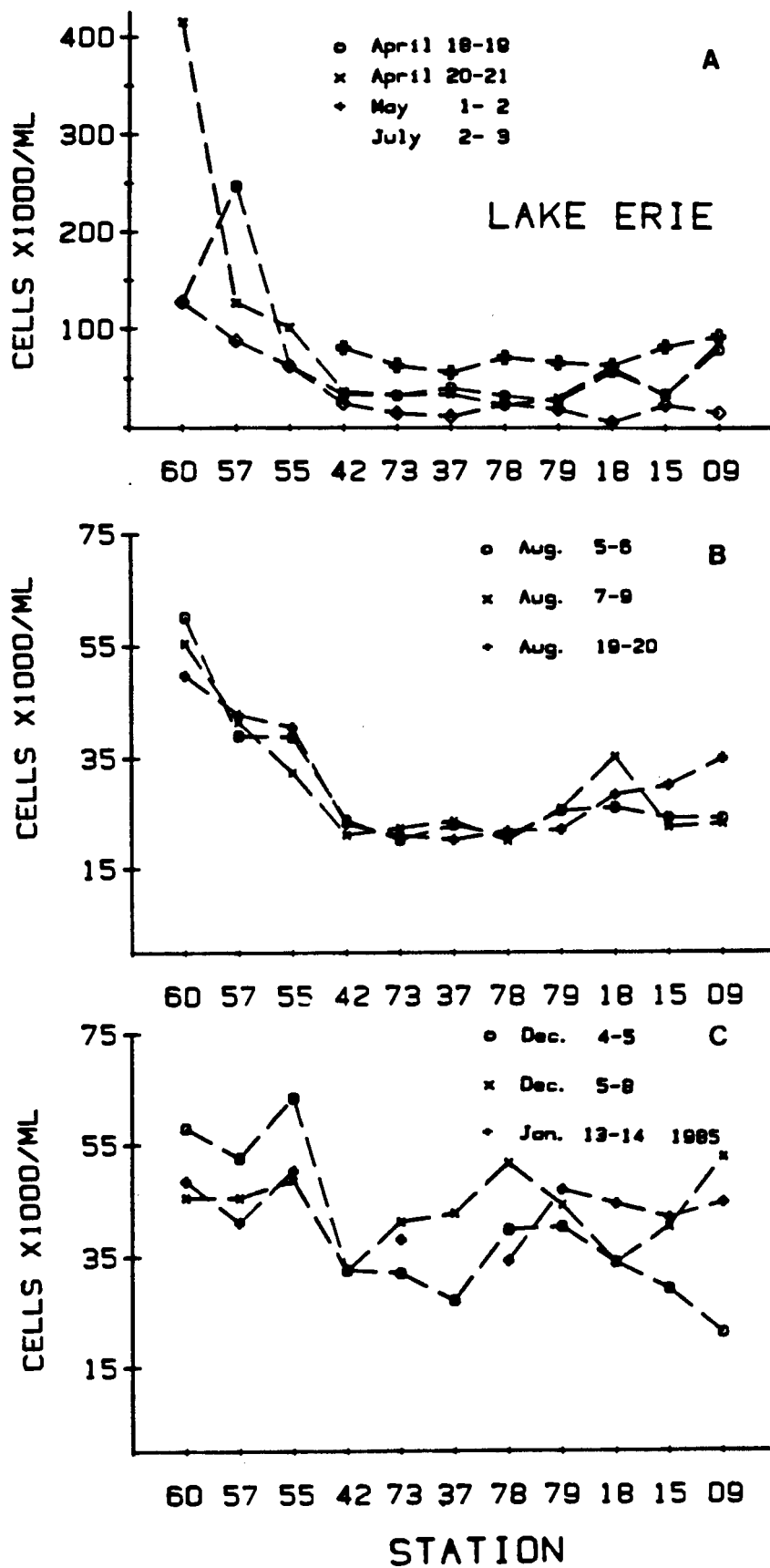


FIGURE 48'. Geographical distribution of phytoplankton abundance on all cruises, Lake Erie, 1984-85.



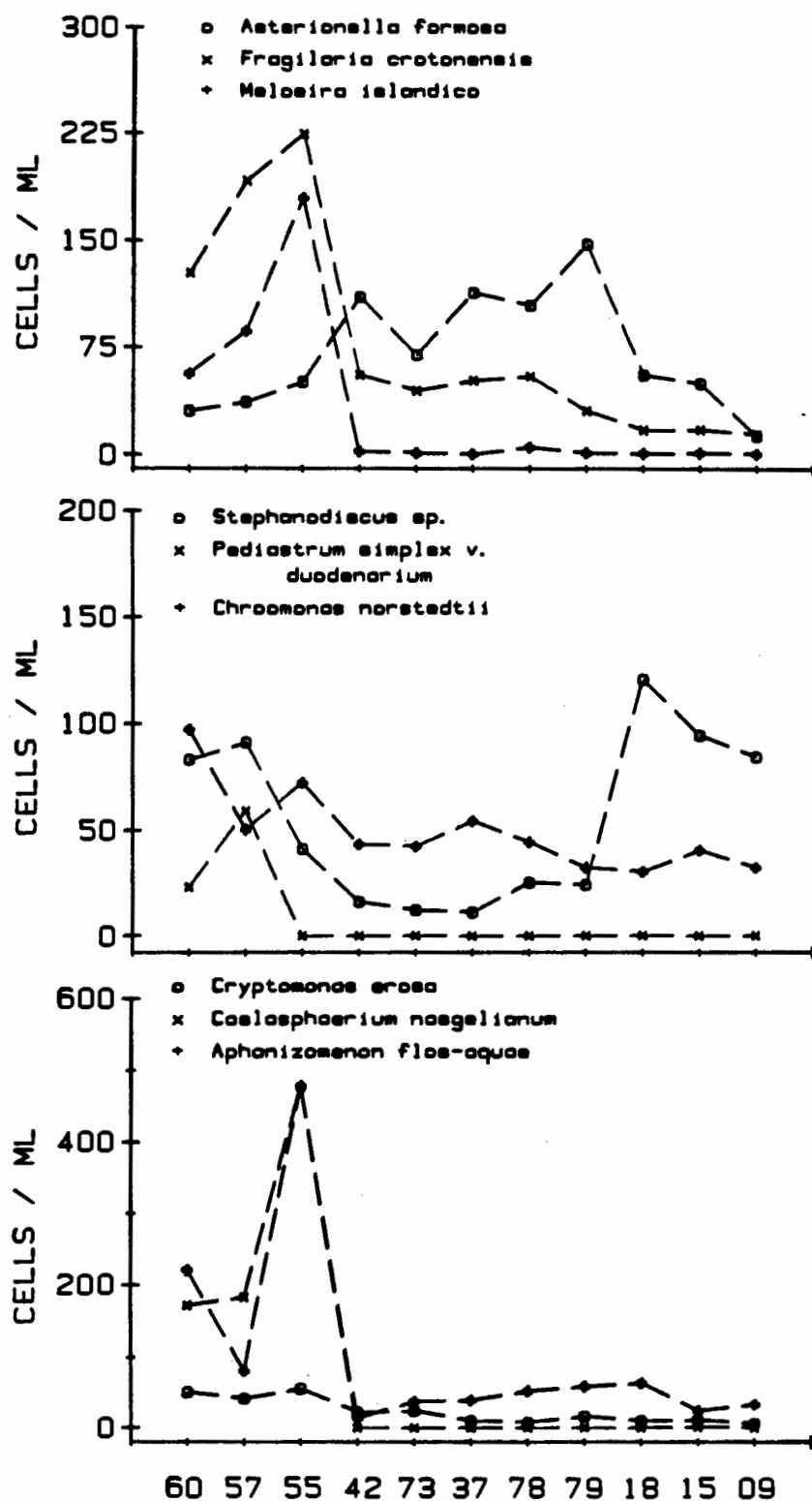


FIGURE 49. Geographical distribution of selected species, Lake Erie, 1984-85.

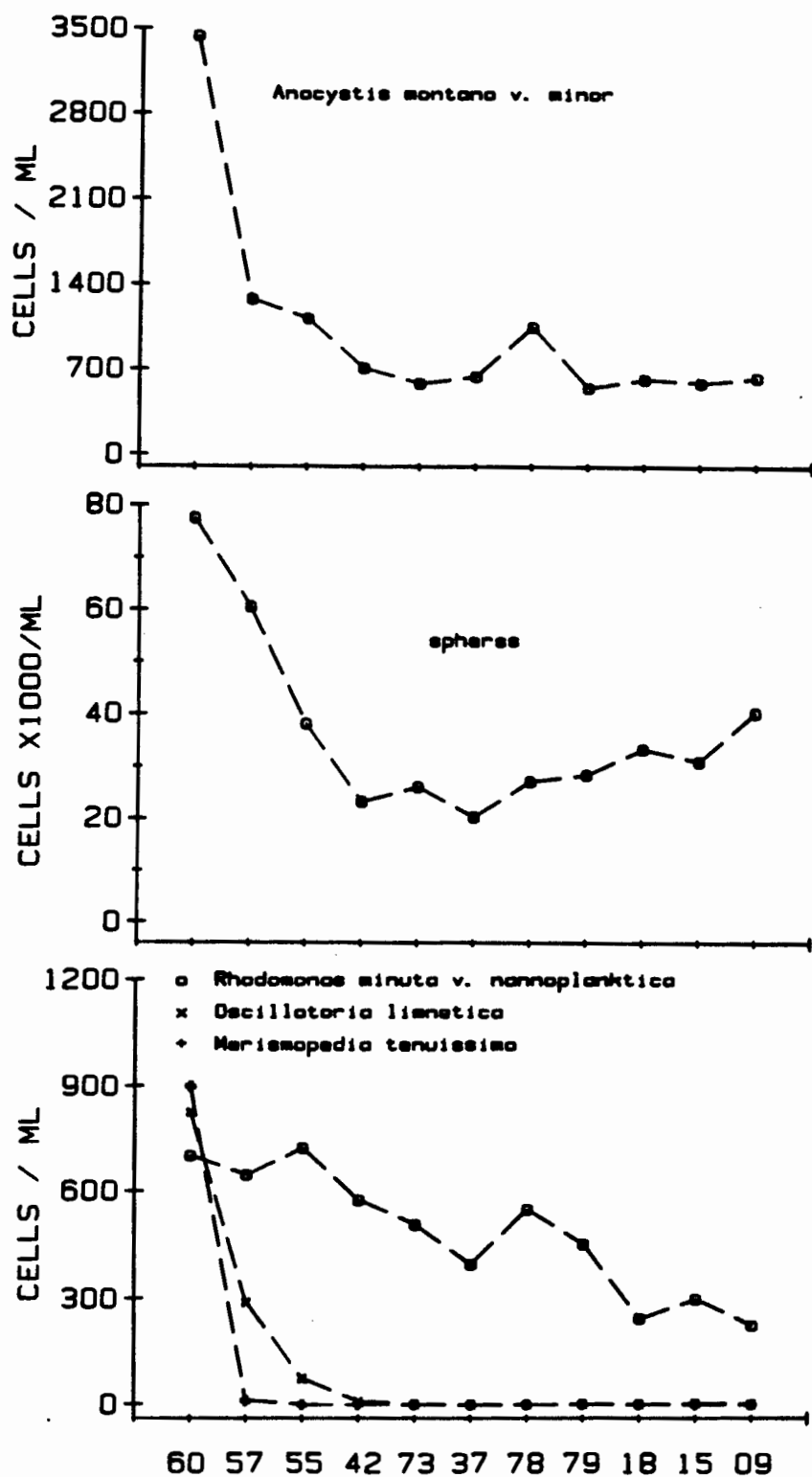


FIGURE 50. Geographical distribution of selected species, Lake Erie, 1984-85.

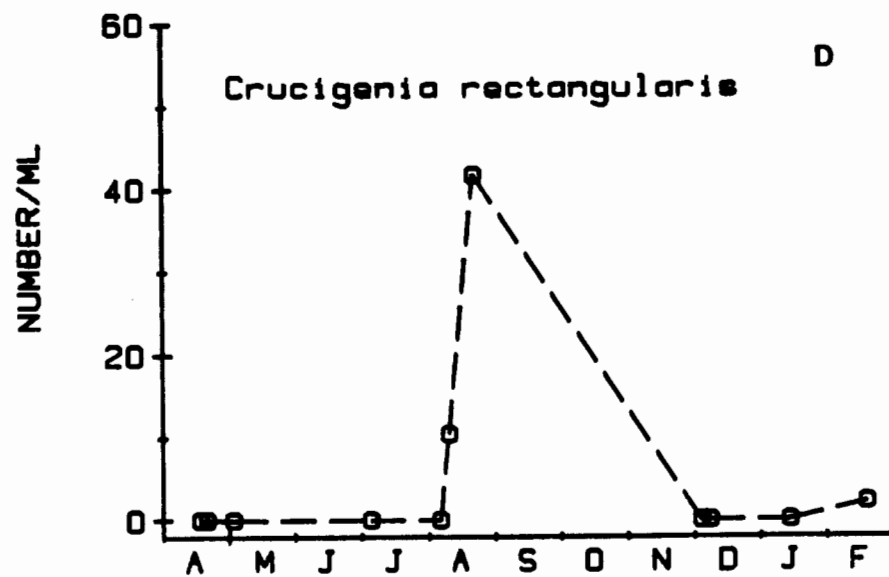
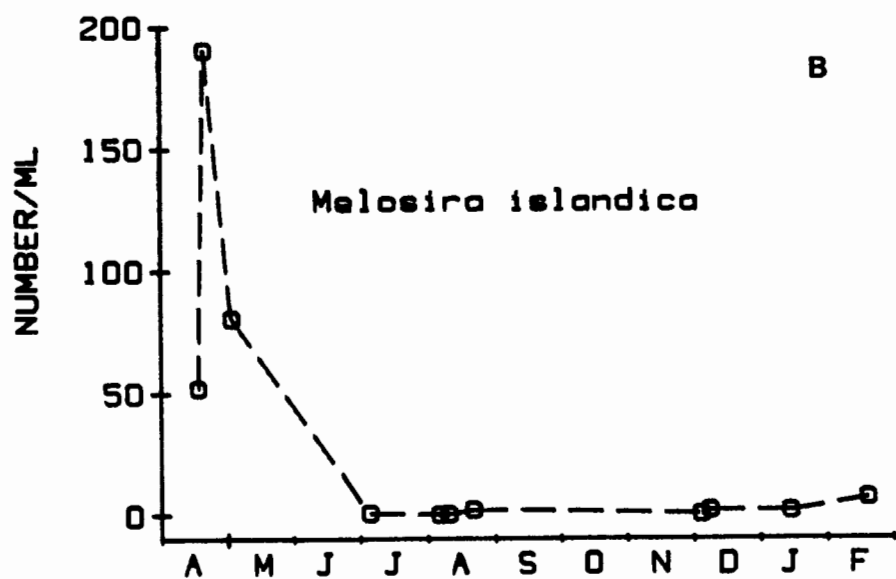
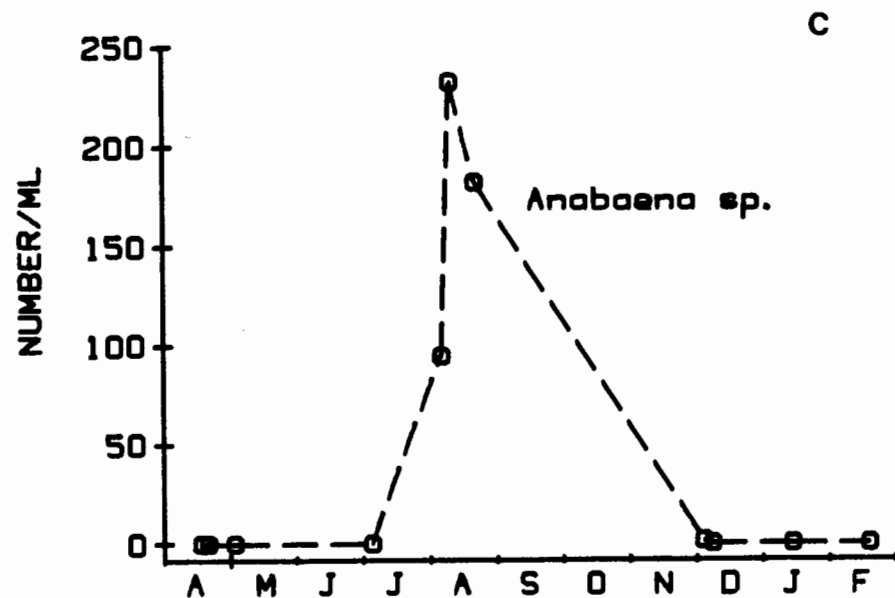
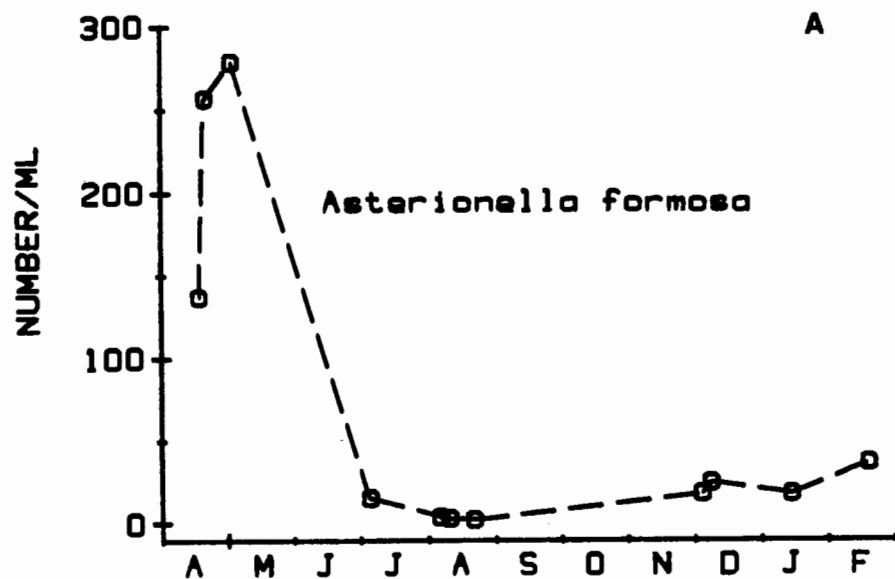


FIGURE 51. Mean seasonal distribution of a) *Asterionella formosa*, b) *Melosira islandica*, c) *Anabaena* sp. and d) *Crucigenia rectangularis*, Lake Erie

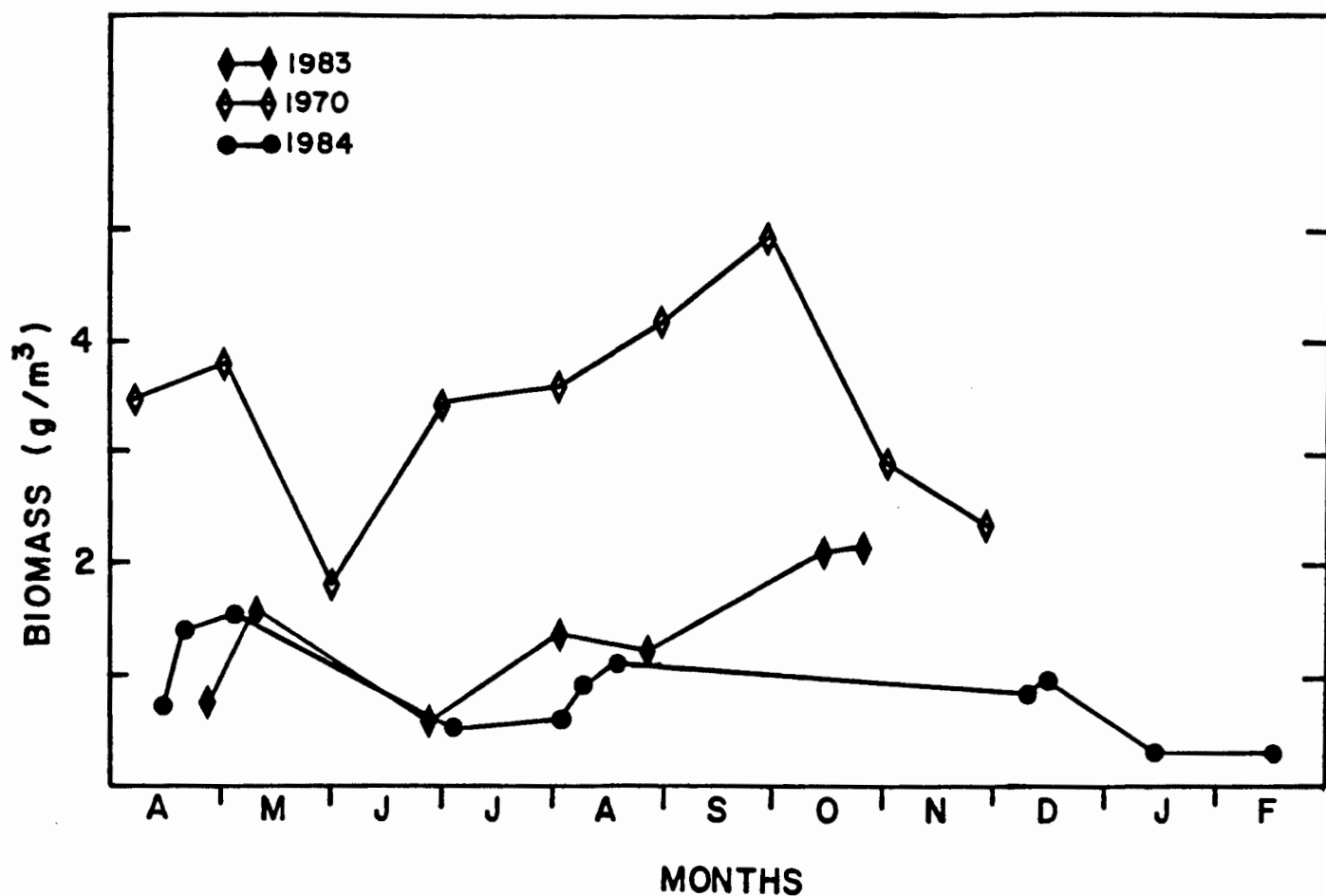


FIGURE 52. Seasonal fluctuation of weighted mean phytoplankton biomass in 1970, 1983 and 1984, Lake Erie. 1970 data modified from Munawar and Munawar (1976). 1983 data from Makarewicz (1987). Values are corrected by using the weighting factors of 15.6%, 59.6% and 24.6% for the western, central and eastern basins (after Munawar and Munawar 1976).

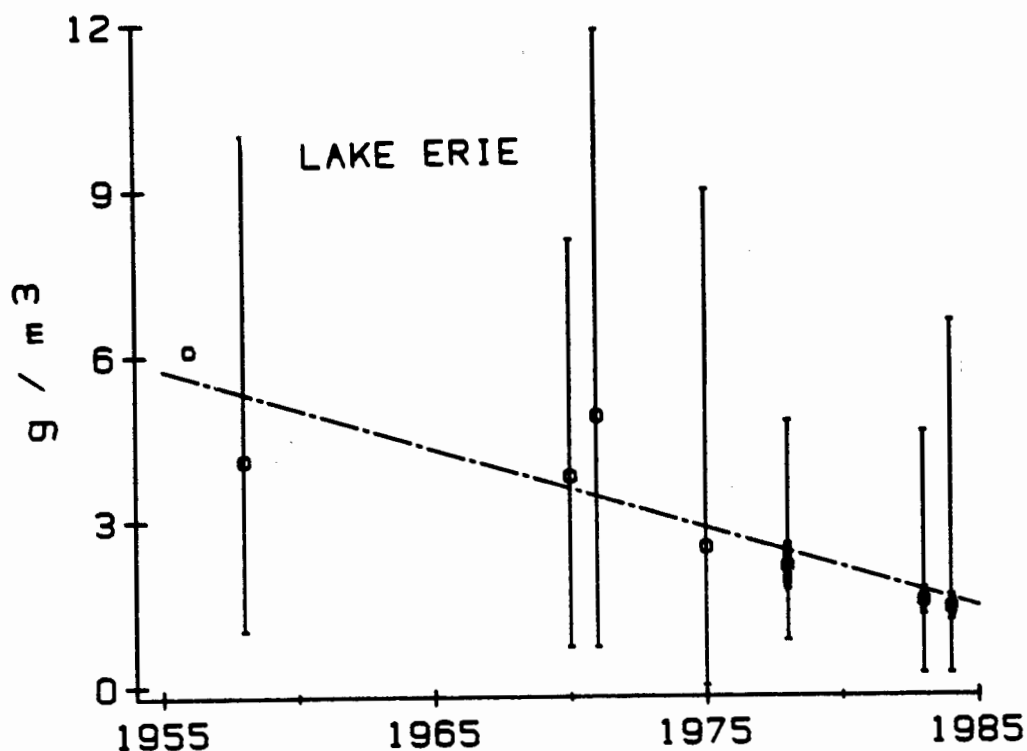


FIGURE 53. Regression ( $r^2=79.2\%$ ) of phytoplankton biomass versus time in western Lake Erie. Modified from Gladish and Munawar (1980). 1956-58 data are from the Bass Island region. 1970 data from Point Pelee and near the mouth of Detroit River. 1975-76 data are from northern portions of the western basin. 1978 data are from similar geographic areas as 1970 (Devault and Rockwell 1986). 1979 data are not included because of a reduced sampling regime and other technical difficulties (Devault and Rockwell 1986). 1983-84 data are from Stations 60, 57 and 55. Except for the 1956 and the 1957-58 data sets, all enumeration was by the Utermohl technique. In 1956 and 1957-58, a settling technique was used, but counts were not made on an inverted microscope. Thin vertical lines are the range. Wide vertical lines are the standard error.

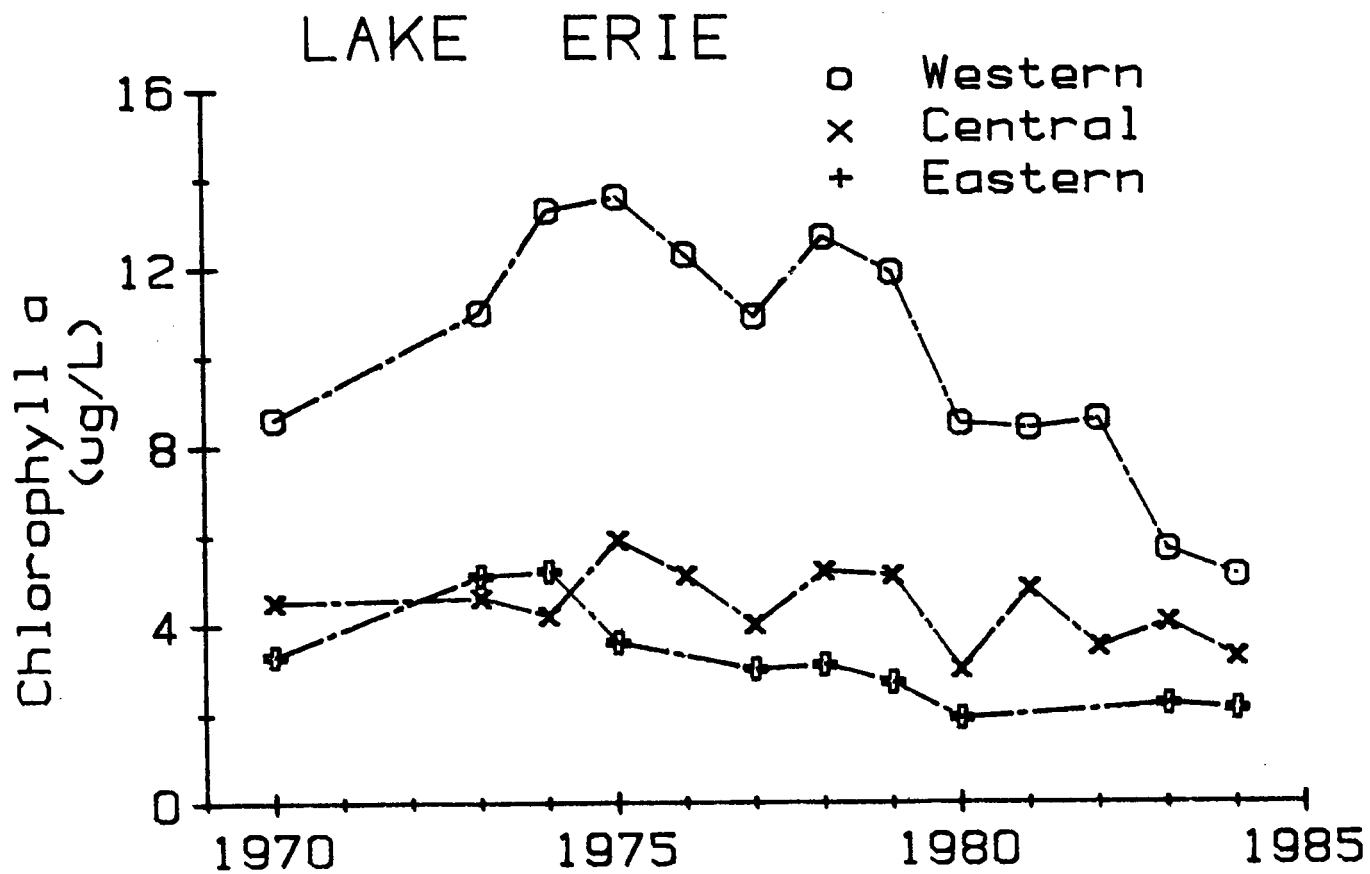


Figure 54. Time trend in annual cruise mean concentration of corrected chlorophyll a since 1970. Data from Rathke (1984) and this study.

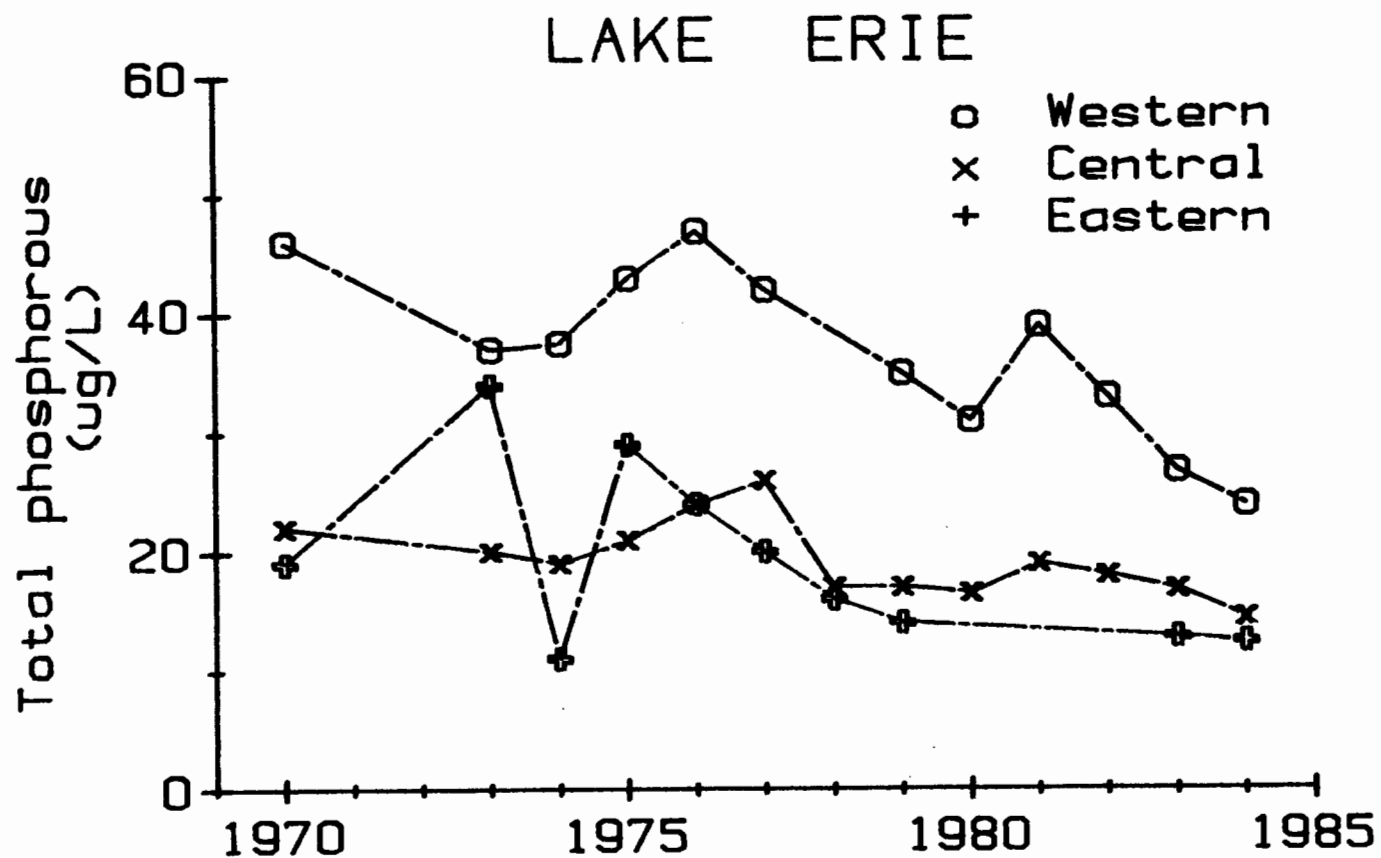


Figure 55. Time trend in annual cruise average of total phosphorus since 1970, Lake Erie. Data are from Depinto et al (1986) and this study.

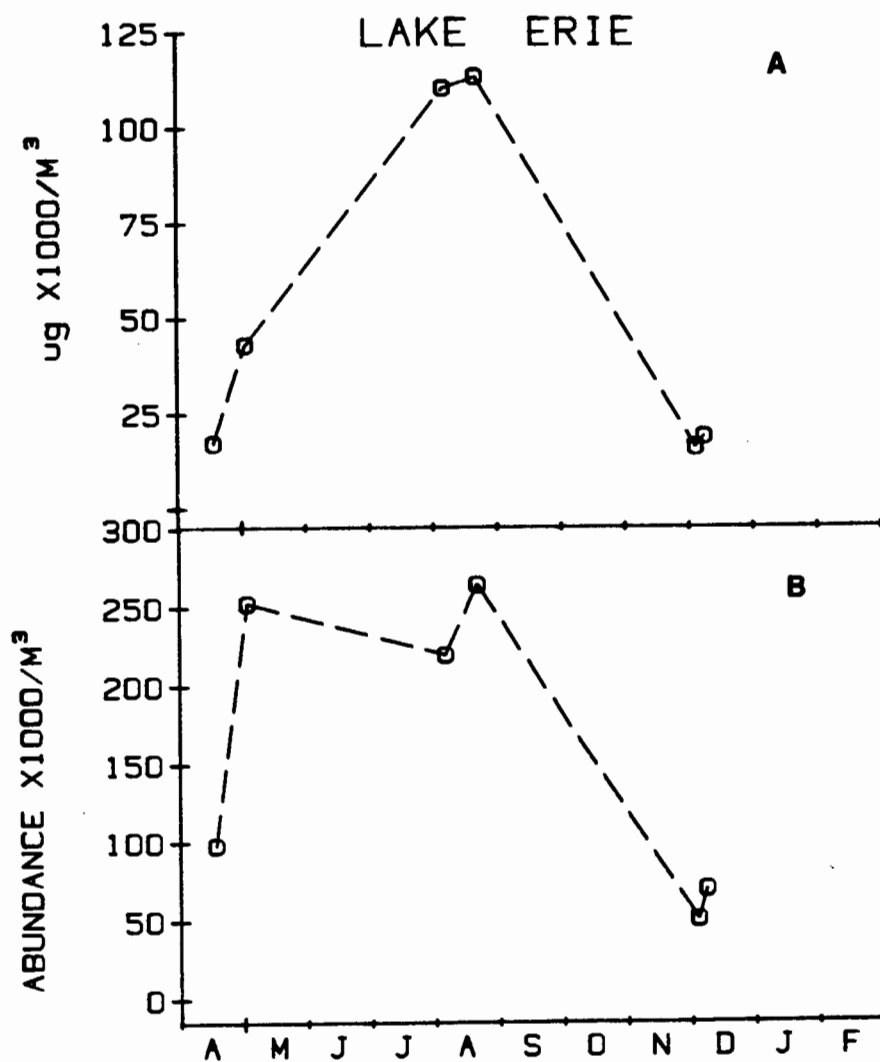


FIGURE 56. Seasonal zooplankton abundance and biomass in Lake Erie, 1984. Short hauls are plotted.



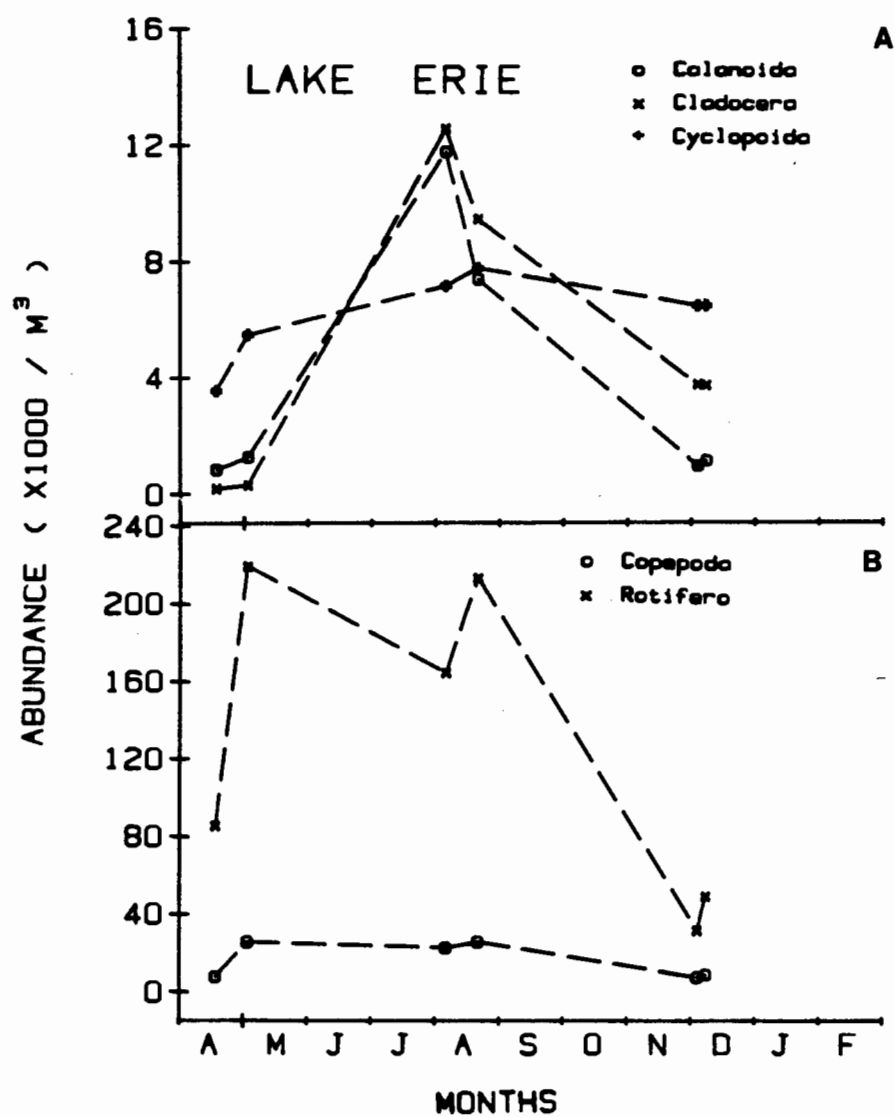


FIGURE 57. Seasonal abundance distribution of zooplankton groups in Lake Erie, 1984. Copepoda refer to the nauplius stage of the Copepoda.

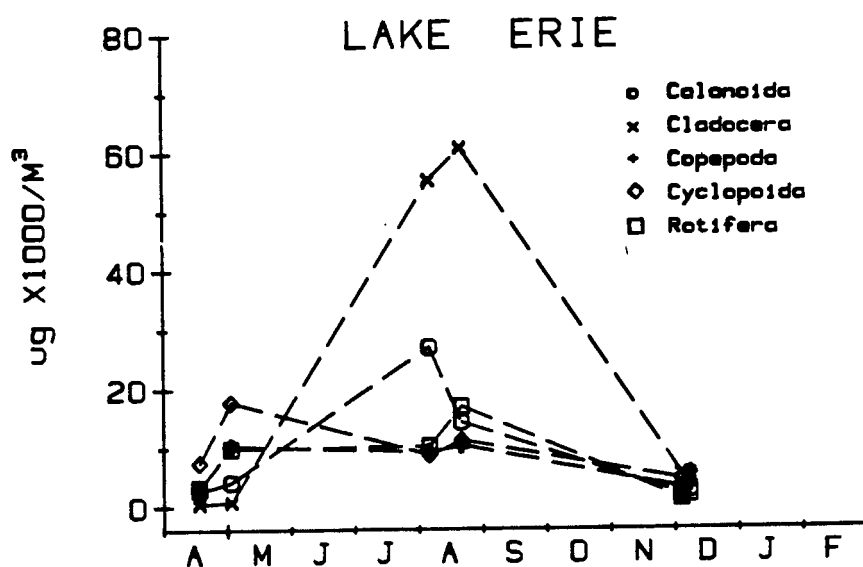


FIGURE 58. Seasonal biomass distribution of zooplankton groups in Lake Erie, 1984. Copepoda refer to the nauplius stage of the Copepoda.

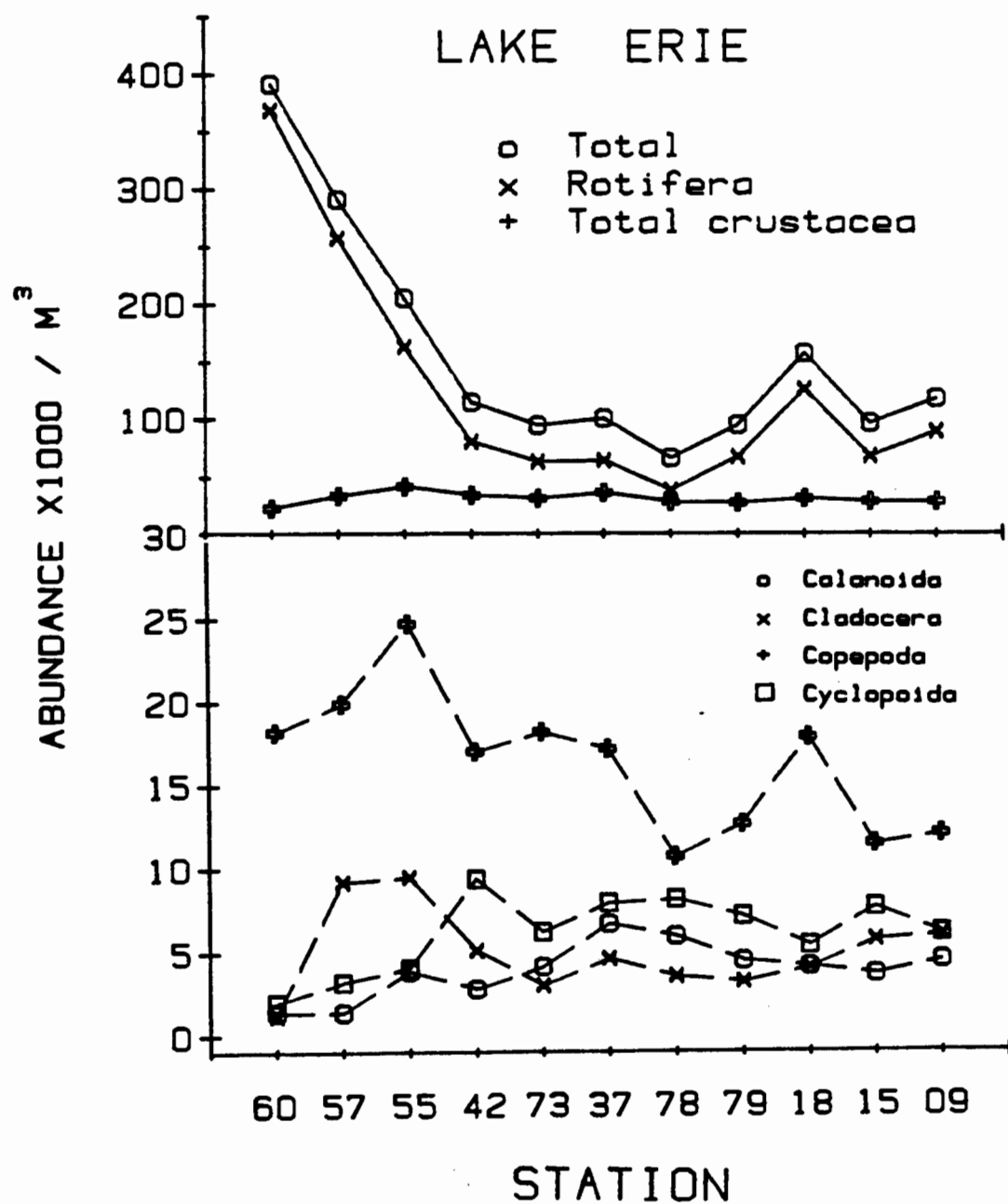


FIGURE 59. Geographical distribution (numerical) of zooplankton groups in Lake Erie, 1984. Copepoda refer to the nauplius stage of the Copepoda.

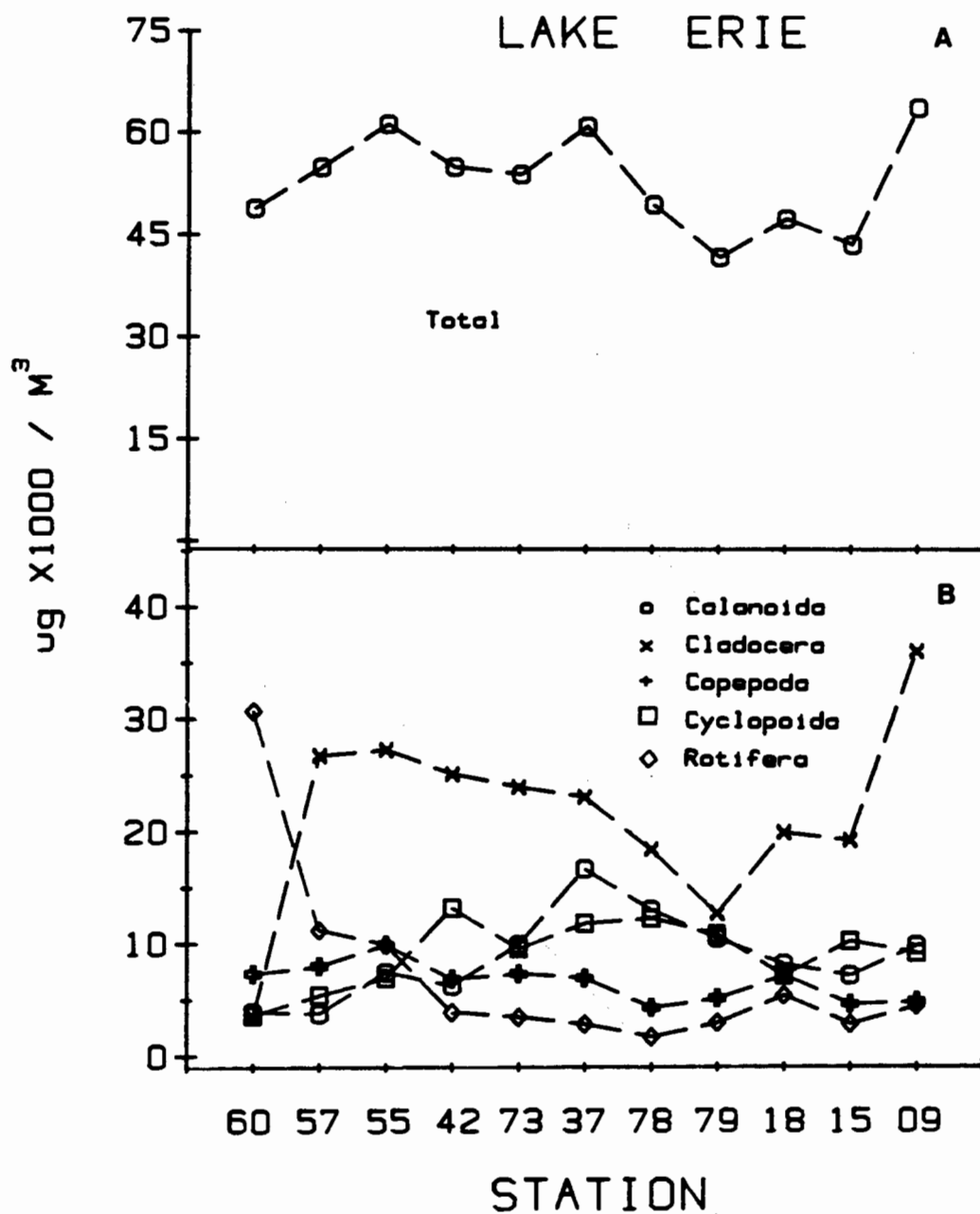


FIGURE 60. Geographical distribution (biomass) of zooplankton groups, 1984. Copepoda refer to the nauplius stage of the Copepoda, Lake Erie

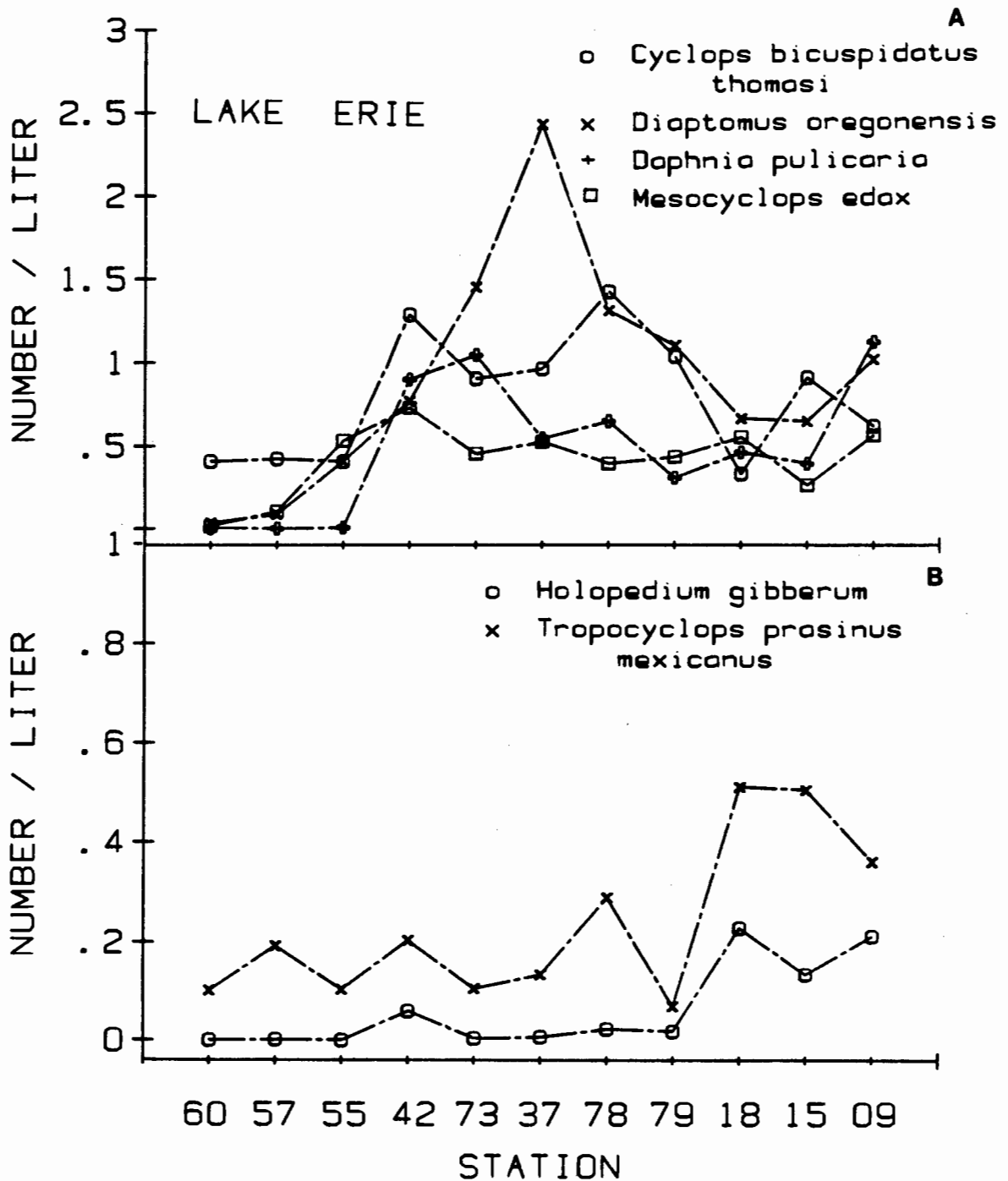


FIGURE 61. Geographical distribution of selected Crustacea in Lake Erie, 1984.

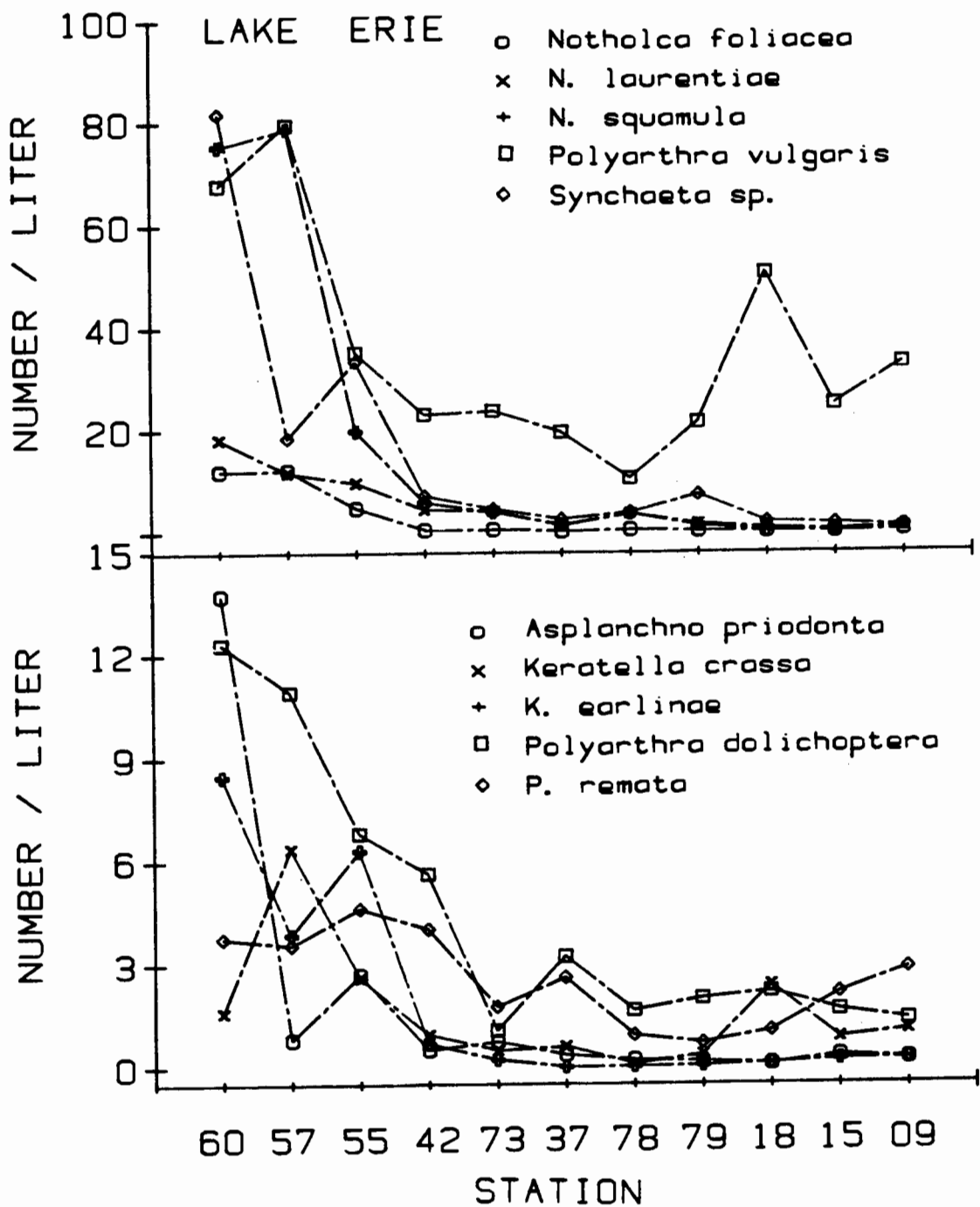


FIGURE 62. Geographical distribution of selected Rotifera in Lake Erie, 1984.

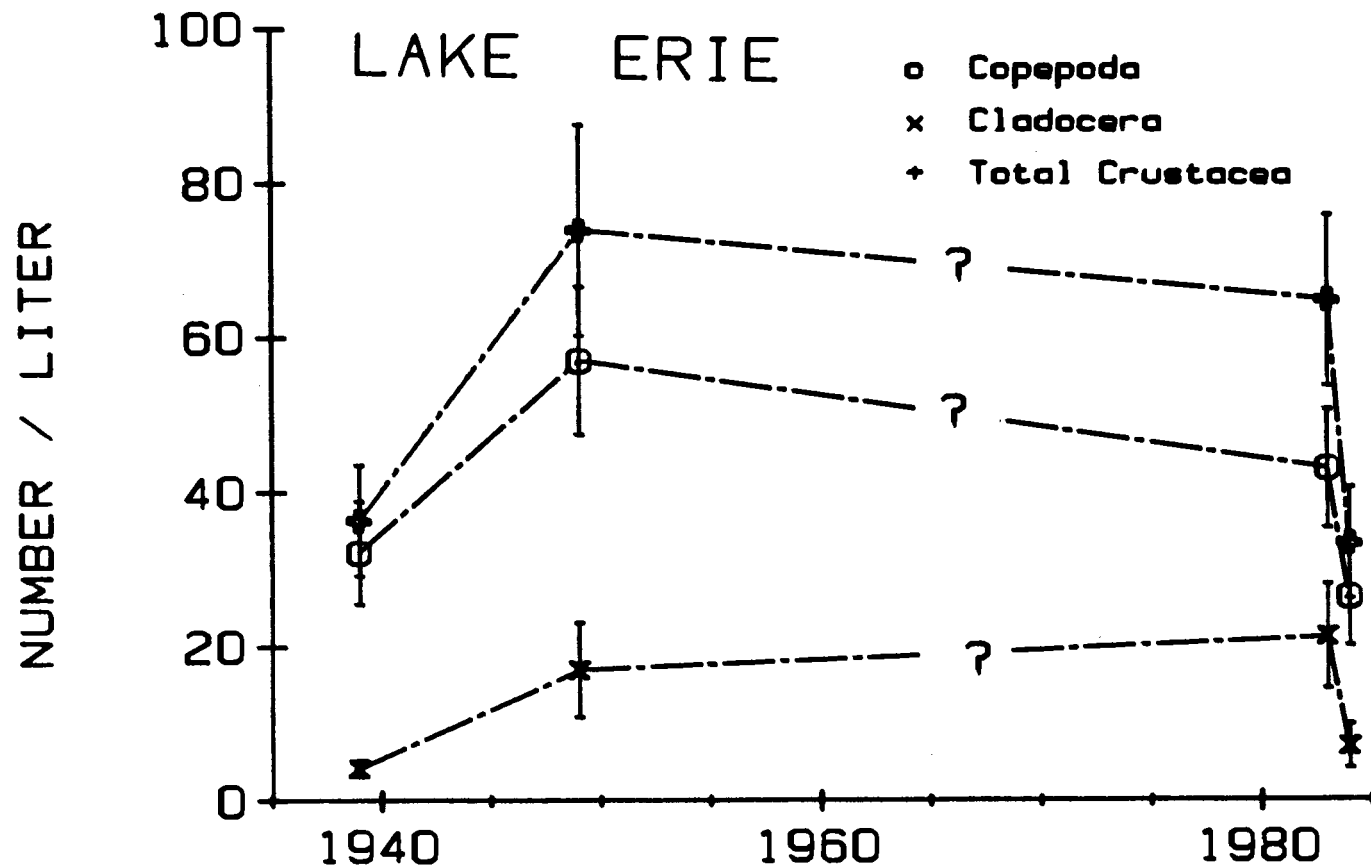


FIGURE 63. Crustacean zooplankton abundance since 1939 in the western basin of Lake Erie. 1939 data are from Chandler (1940; April-October). 1949 data are from Bradshaw (1964; April-October). 1983 data are from Makarewicz (1987; April-November) and 1984 (This study; April-December). Values are the mean  $\pm$  Standard Error.

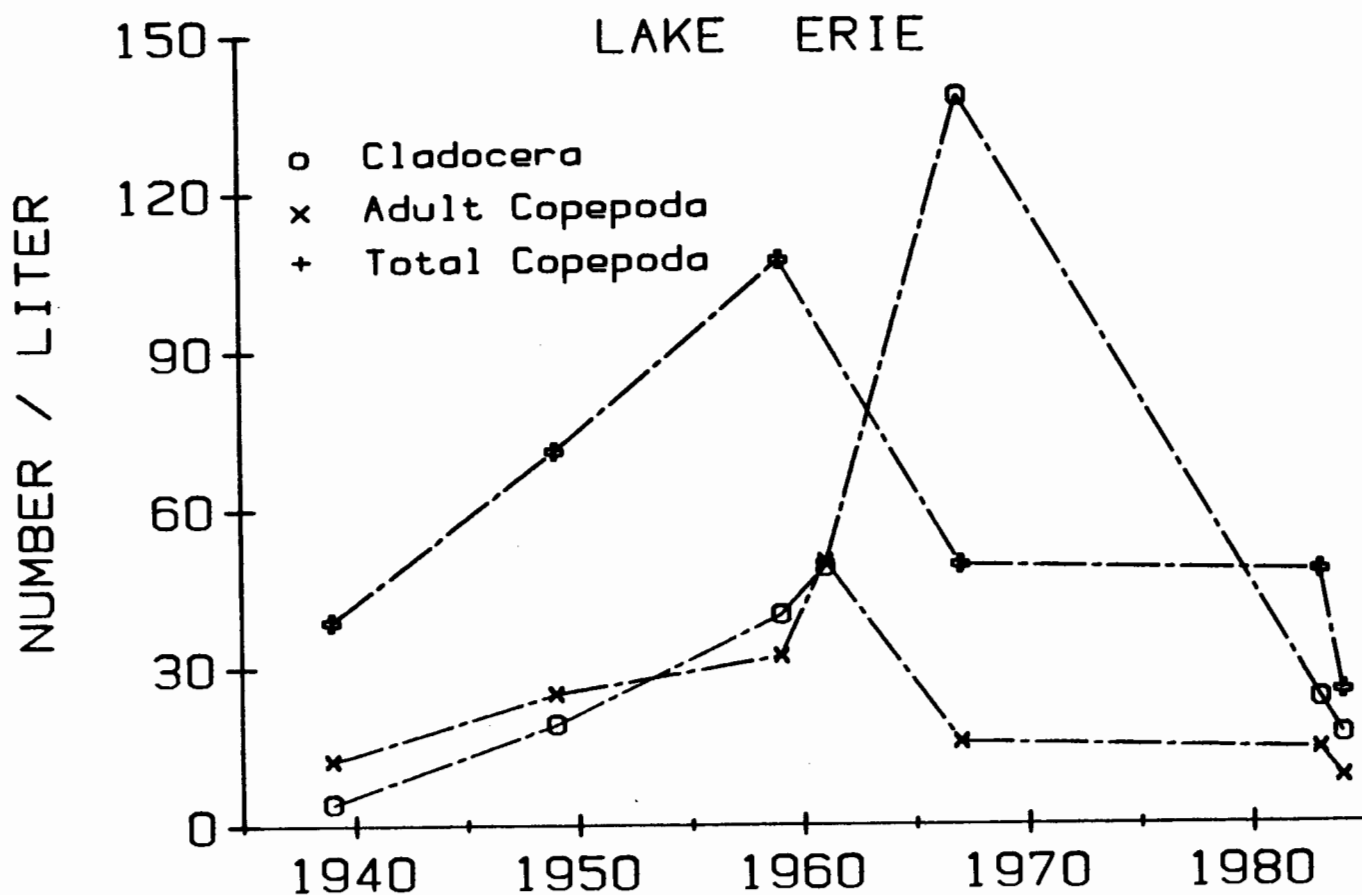


FIGURE 64. July and August abundance of Cladocera and Copepoda in the western basin of Lake Erie since 1939. Total Copepoda refers to adults plus the nauplius stage. Data are from Chandler (1940), Bradshaw (1964), Hubschman (1960), Britt et al. (1973), Davis (1969b) Makarewicz (1987) and this study. The number of adults and total copepods in 1939 and 1959 follow Bradshaw's (1964) calculations.



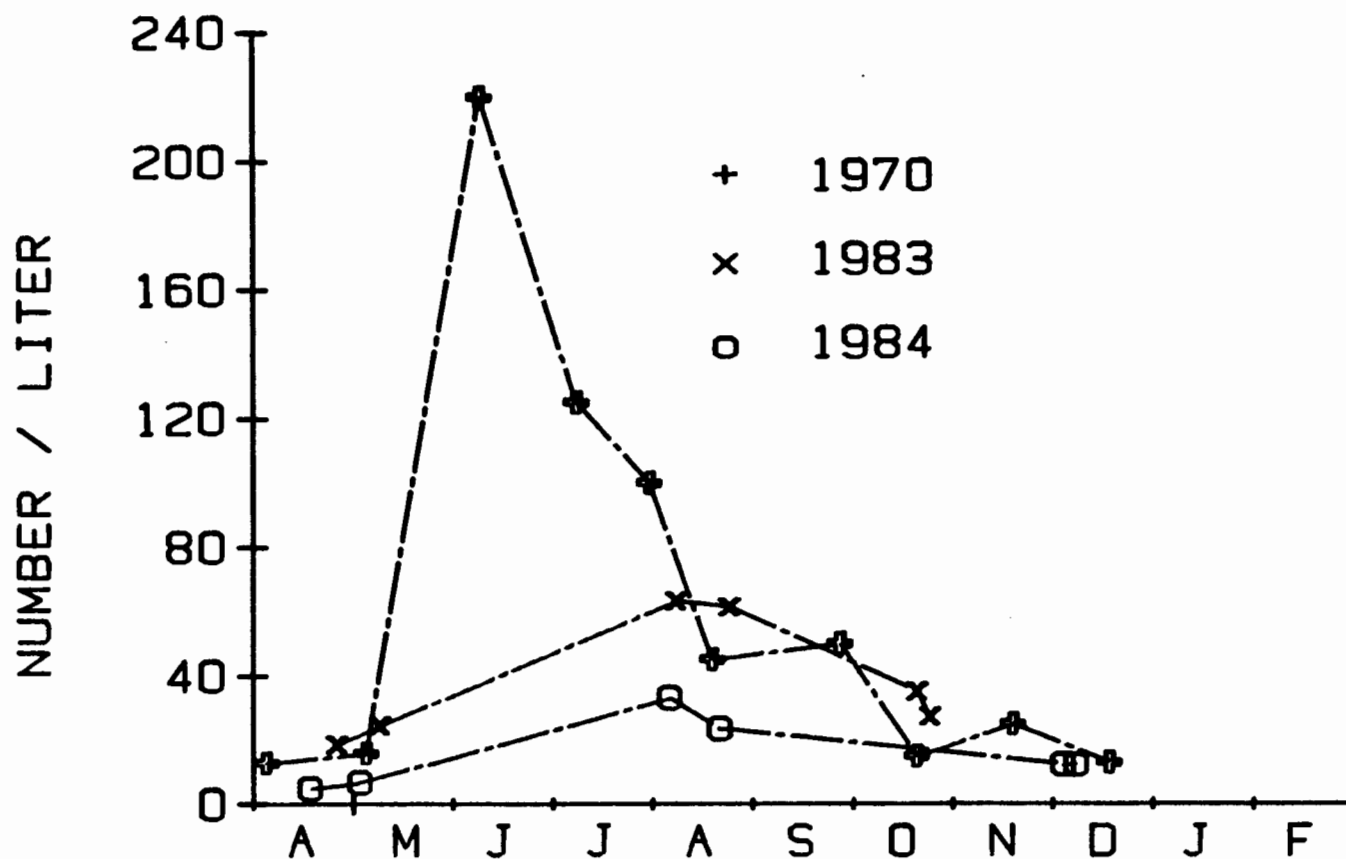
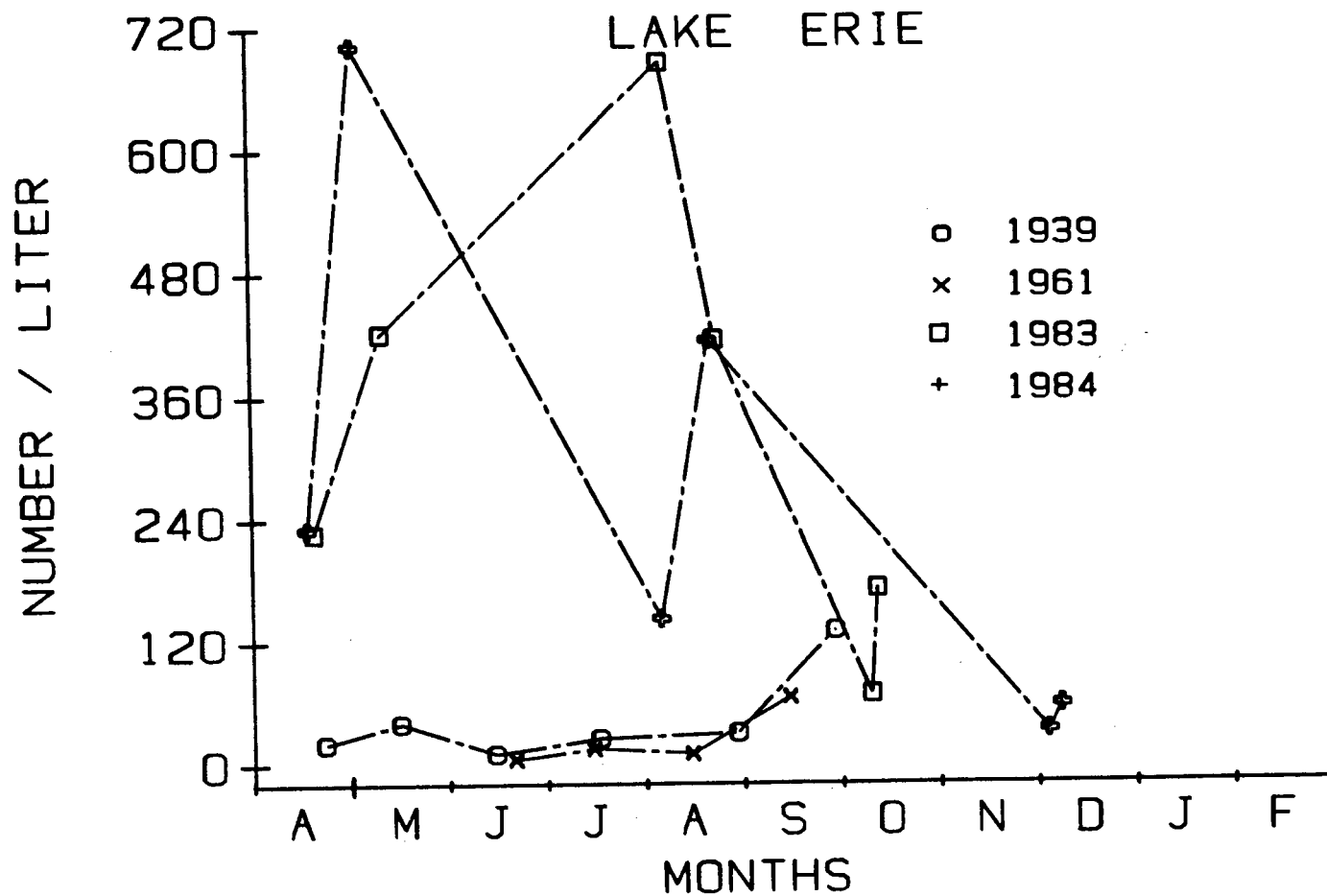


FIGURE 65. Seasonal fluctuation of weighted mean Crustacea (nauplii excluded) abundance in 1970, 1983, 1984, Lake Erie. 1970 data follow Watson and Carpenter (1974). 1983 data from Makarewicz (1987). 1983 and 1984 values are corrected by using the weighting factors of 15.6%, 59.6% and 24.6% for the western, central and eastern basins (after Munawar and Munawar 1976).



**FIGURE 66.** Seasonal fluctuation of Rotifera in the western basin of Lake Erie from 1939 - 1983. Sources: 1939 - Chandler (1940); 1961 - Britt et al. (1973); 1983 - Makarewicz (1987). The 1970 samples of Nalepa (1972) are not included because they are from the far western end of the basin and may not be represented of the entire basin.

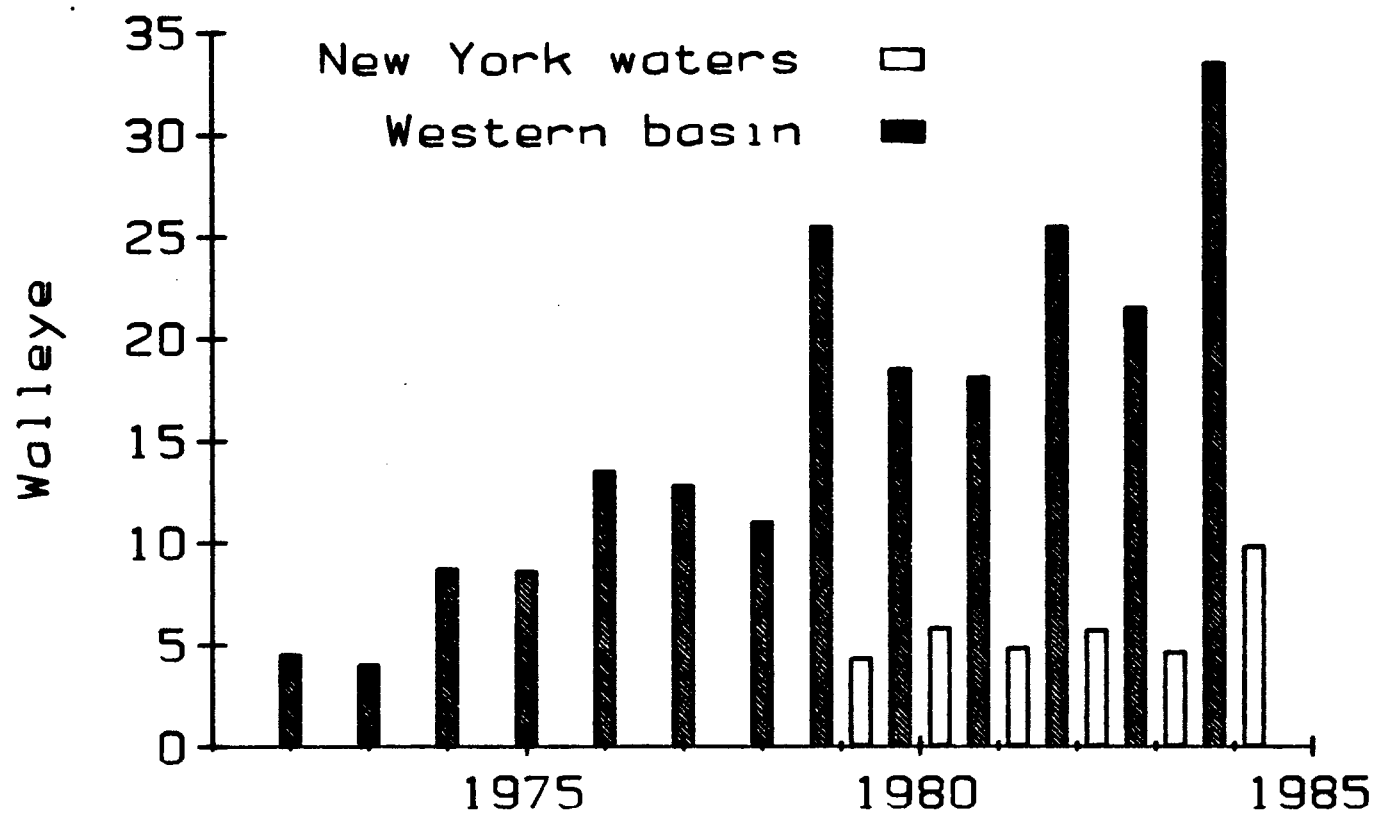


Figure 67. Abundance (millions of fish) of fishable walleye (age 2+) in western Lake Erie (Ohio waters). For New York waters, values represent catch per 22 net meters in variable mesh nets. Data from Ohio Department of Natural Resources (1985) and New York State Department of Environmental Conservation (1985).

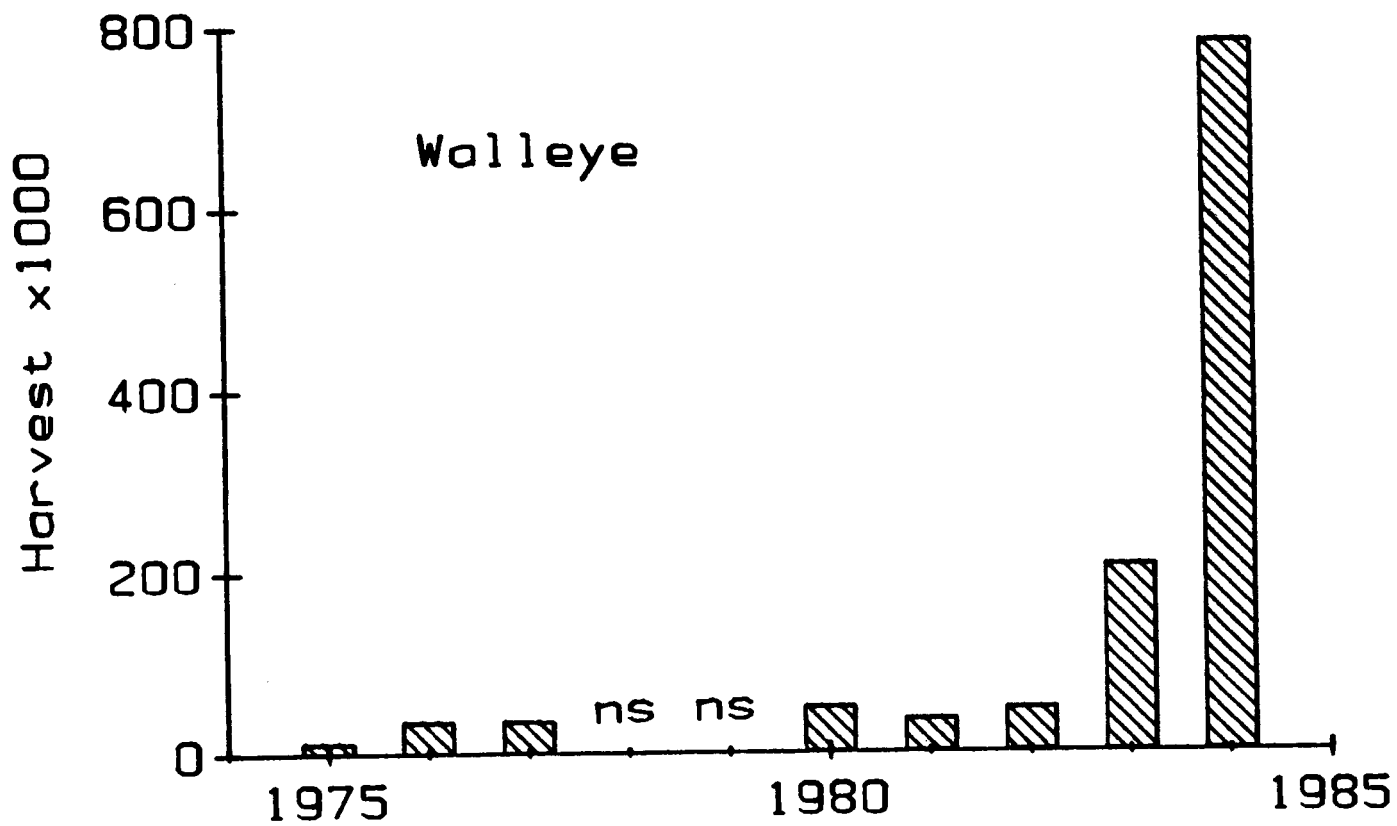


Figure 68. Sport angler harvest of walleye from the central basin of Lake Erie. Modified from the Ohio Department of Natural Resources.

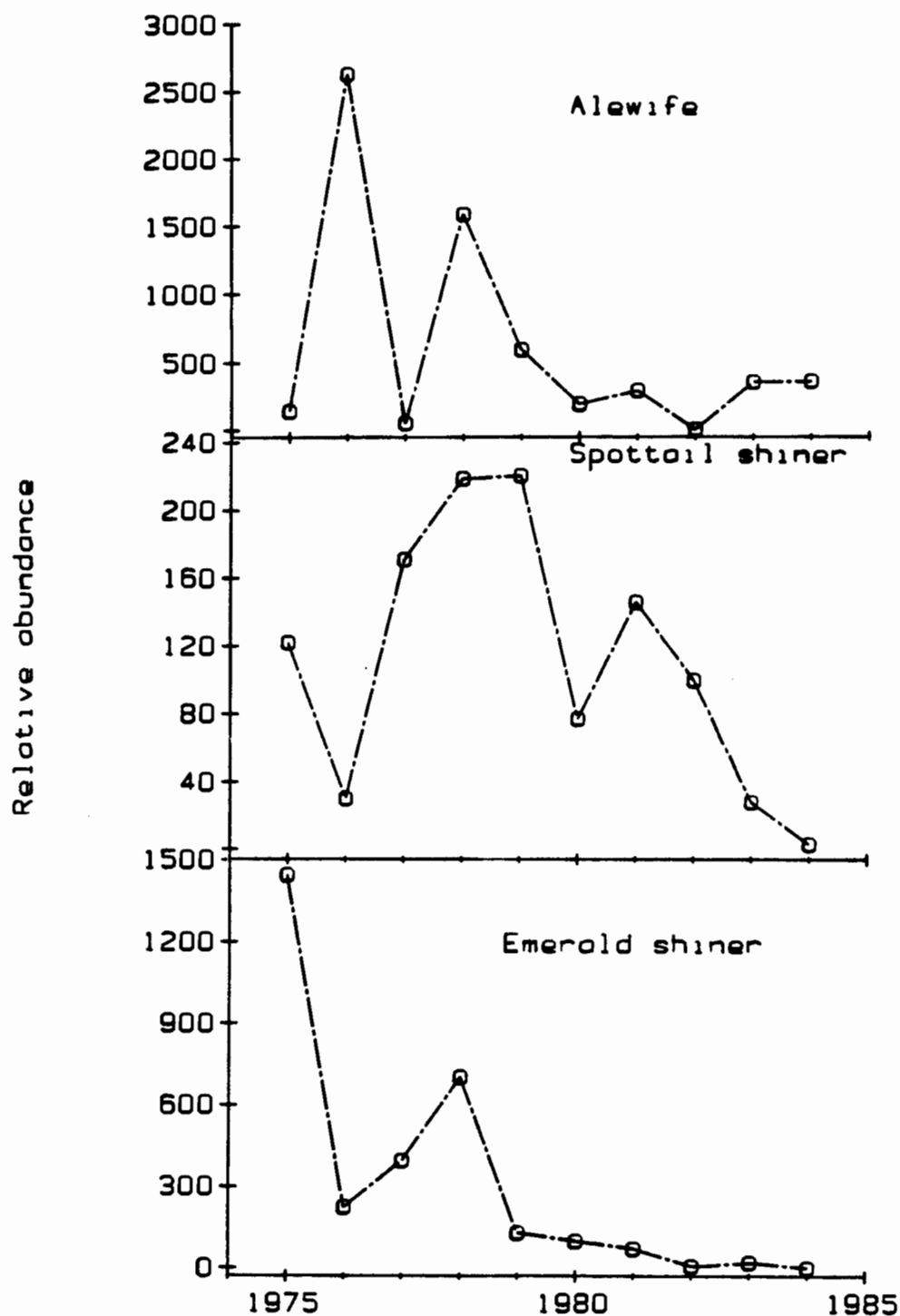


Figure 69. Time trend of emerald and spottail shiner abundance in the central basin and alewife from the western basin of Lake Erie. Values represent the number per trawling hour. Data from Ohio Department of Natural Resources (1985).

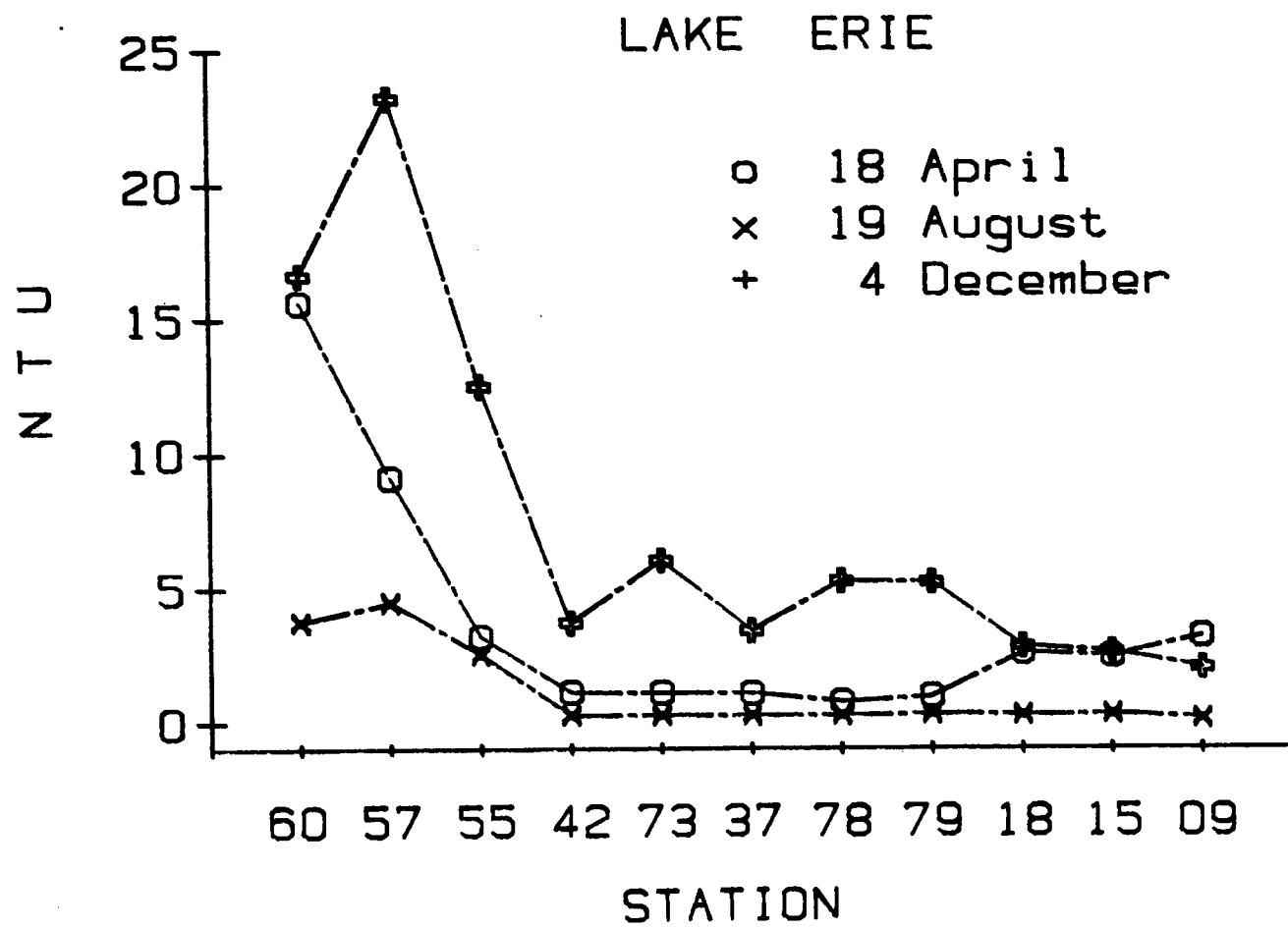


Figure 70. Seasonal and geographical turbidity trends in Lake Erie, 1984.

Table A  
Phytoplankton  
Species List: Lake Michigan

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Achnanthes affinis</i>	Grun.
	<i>Achnanthes biasoletiana</i>	(Kutz.) Grun.
	<i>Achnanthes clevei</i>	Grun.
	<i>Achnanthes clevei</i> v. <i>rostrata</i>	Hust.
	<i>Achnanthes conspicua</i>	A. Mayer
	<i>Achnanthes deflexa</i>	Reim. in Patr. & Reim.
	<i>Achnanthes exigua</i>	Grun.
	<i>Achnanthes lanceolata</i> v. <i>constricta</i>	(Grun.) Hust.
	<i>Achnanthes flexella</i>	(Kutz.) Brun.
	<i>Achnanthes hauckiana</i>	Grun.
	<i>Achnanthes lanceolata</i>	(Breb.) Greg.
	<i>Achnanthes lanceolata</i> v. <i>dubia</i>	Grun.
	<i>Achnanthes lapponica</i> v. <i>ninckei</i>	(Guerm. & Mang.) Reim.
	<i>Achnanthes lapponica</i> v. <i>ninckei</i> ?	(Guerm. & Mang.) Reim.
	<i>Achnanthes linearis</i>	(W. Sm.) Grun.
	<i>Achnanthes linearis</i> fo. <i>curta</i>	H.L. Sm.
	<i>Achnanthes minutissima</i>	Kutz.
	<i>Achnanthes oestrupii</i> v. <i>lanceolata</i>	Hust.
	<i>Achnanthes</i> sp.	
	<i>Achnanthes suchlandtii</i>	Hust.
	<i>Actinocyclus normanii</i> f. <i>subsalsus</i>	(Juhl.-Dannf.) Hust.
	<i>Amphipleura pellucida</i>	(Kutz.) Kutz.
	<i>Amphora ovalis</i>	(Kutz.) Kutz.
	<i>Amphora ovalis</i> v. <i>affinis</i>	(Kutz.) V.H. ex DeT.
	<i>Amphora ovalis</i> v. <i>pediculus</i>	(Kutz.) V.H. ex DeT.
	<i>Amphora perpusilla</i>	(Grun.) Grun.
	<i>Amphora</i> sp.	
	<i>Amphora thumensis</i>	(Mayer) A. Cl.
	<i>Anomoeoneis vitrea</i>	(Grun.) Patr. & Reim.
	<i>Asterionella formosa</i>	Hass.
	<i>Caloneis</i> sp.	
	<i>Cocconeis diminuta</i>	Pant.
	<i>Cocconeis disculus</i>	(Schum.) Cl.
	<i>Cocconeis placentula</i> v. <i>euglypta</i>	(Ehr.) Cl.
	<i>Cocconeis placentula</i> v. <i>lineata</i>	(Ehr.) Cl.
	<i>Cocconeis thumensis</i>	A. Mayer
	<i>Cyclotella antiqua</i>	W. Sm.
	<i>Cyclotella antiqua</i> ?	W. Sm.
	<i>Cyclotella atomus</i>	Pant.
	<i>Cyclotella comensis</i>	Grun.
	<i>Cyclotella comensis</i> - auxospore	
	<i>Cyclotella comensis</i> v. 1	
	<i>Cyclotella comensis</i> v. 2	
	<i>Cyclotella comta</i>	(Ehr.) Kutz.
	<i>Cyclotella comta</i> - auxospore	
	<i>Cyclotella comta</i> v. <i>oligactis</i>	(Ehr.) Grun.
	<i>Cyclotella cryptica</i>	Reim. et al.
	<i>Cyclotella kuetzingiana</i>	Thw.
	<i>Cyclotella meneghiniana</i>	Kutz.
	<i>Cyclotella michiganiana</i>	Skv.
	<i>Cyclotella michiganiana</i> - auxospore	
	<i>Cyclotella ocellata</i>	Pant.



## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Cyclotella operculata</i>	(Ag.) Kutz.
	<i>Cyclotella operculata unipunctata</i>	Hust.
	<i>Cyclotella pseudostelligera</i>	Hust.
	<i>Cyclotella</i> sp.	
	<i>Cyclotella</i> sp. #1	
	<i>Cyclotella</i> sp. - auxospore	
	<i>Cyclotella stelligera</i>	(Cl. & Grun.) V.H.
	<i>Cymatopleura elliptica</i>	(Breb.) W.Sm.
	<i>Cymatopleura solea</i>	(Breb. & Godey) W. Sm.
	<i>Cymbella cesatii</i>	(Rabh.) Grun. ex A.S.
	<i>Cymbella cistula</i> v. <i>gibbosa</i>	Brun.
	<i>Cymbella delicatula</i>	Kutz.
	<i>Cymbella microcephala</i>	Grun.
	<i>Cymbella minuta</i>	Hilse
	<i>Cymbella minuta</i> v. <i>silesiaca</i>	(Bleisch) Reim.
	<i>Cymbella norvegica</i>	Grun.
	<i>Cymbella prostrata</i> v. <i>auerswaldii</i>	(Rabh.) Reim.
	<i>Cymbella sinuata</i>	Greg.
	<i>Cymbella</i> sp.	
	<i>Cymbella triangulum</i>	(Ehr.) Cl.
	<i>Denticula tenuis</i> v. <i>crassula</i>	(Nag.) W. & G.S. West.
	<i>Diatoma tenue</i>	Ag.
	<i>Diatoma tenue</i> v. <i>elongatum</i>	Lyngb.
	<i>Diploneis elliptica</i>	(Kutz.) Cl.
	<i>Diploneis oculata</i>	(Breb.) Cl.
	<i>Diploneis parma</i>	Cl.
	<i>Diploneis</i> sp.	
	<i>Entomoneis ornata</i>	(J.W. Bail.) Reim.
	<i>Eunotia incisa</i>	W. Sm.
	<i>Fragilaria brevistriata</i>	Grun.
	<i>Fragilaria brevistriata</i> v. <i>inflata</i>	(Pant.) Hust.
	<i>Fragilaria brevistriata</i> v. <i>subcapitata</i>	Grun.
	<i>Fragilaria capucina</i>	Desm.
	<i>Fragilaria capucina</i> v. <i>mesolepta</i>	(Rabh.) Grun.
	<i>Fragilaria construens</i>	(Ehr.) Grun.
	<i>Fragilaria construens</i> v. <i>binodis</i>	(Ehr.) Grun.
	<i>Fragilaria construens</i> v. <i>minuta</i>	Temp. & Per.
	<i>Fragilaria construens</i> v. <i>subsalina</i>	Hust.
	<i>Fragilaria construens</i> v. <i>venter</i>	(Ehr.) Grun.
	<i>Fragilaria crotonensis</i>	Kitton
	<i>Fragilaria leptostauron</i>	(Ehr.) Hust.
	<i>Fragilaria pinnata</i>	Ehr.
	<i>Fragilaria pinnata</i> v. <i>intercedens</i>	(Grun.) Hust.
	<i>Fragilaria pinnata</i> v. <i>lancettula</i>	(Schum.) Hust.
	<i>Fragilaria</i> sp.	
	<i>Fragilaria vaucheriae</i>	(Kutz.) Peters.
	<i>Fragilaria vaucheriae</i> v. <i>capitellata</i>	(Grun.) Patr.
	<i>Gomphonema affine</i>	Kutz.
	<i>Gomphonema dichotomum</i>	Kutz.
	<i>Gomphonema gracile</i>	Ehr. em. V.H.
	<i>Gomphonema parvulum</i>	Kutz.
	<i>Gomphonema</i> sp.	

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	Gyrosigma sciense	(Sulliv. & Wormley) Cl.
	Melosira ambigua	(Grun.) O. Mull.
	Melosira distans	(Ehr.) Kutz.
	Melosira granulata	(Ehr.) Ralfs
	Melosira granulata v. angustissima	O. Mull.
	Melosira islandica	O. Mull.
	Melosira italica	(Ehr.) Kutz.
	Melosira italica subsp. subarctica	O. Mull.
	Melosira sp.	
	Meridion circulare	(Greg.) Ag.
	Navicula anglica v. signata	Hust.
	Navicula anglica v. subsalsa	(Grun.) Cl.
	Navicula capitata	Ehr.
	Navicula capitata v. hurgarica	(Grun.) Ross
	Navicula cincta	(Ehr.) Ralfs
	Navicula cryptocephala	Kutz.
	Navicula cryptocephala v. veneta	(Kutz.) Rabh.
	Navicula exigua v. capitata	Patr.
	Navicula graciloides	A. Mayer
	Navicula gregaria	Donk.
	Navicula integra	(W. Sm.) Ralfs
	Navicula jaernefeldtii	Hust.
	Navicula lacustris	Greg.
	Navicula lanceolata	(Ag.) Kutz.
	Navicula meniscus v. upsaliensis	(Grun.) Grun.
	Navicula minima	Grun.
	Navicula pseudoreinhardtii?	Patr.
	Navicula pupula	Kutz.
	Navicula radiosa	Kutz.
	Navicula radiosa v. tenella	(Breb.) Cl. & Moll.
	Navicula reinhardtii	(Grun.) Grun.
	Navicula seminuloides	Hust.
	Navicula seminulum	Grun.
	Navicula sp.	
	Navicula tripunctata	(O.F.Mull.) Bory
	Navicula tripunctata v. schizonemoides	(Breb. ex Grun.) V.H.
	Navicula tuscula	Ehr.
	Navicula viridula	(Kutz.) Ehr.
	Neidum sp. #1	
	Nitzschia acicularioides	Arch. non Hust.
	Nitzschia acicularis	(Kutz.) W. Sm.
	Nitzschia acula	Hantz. ex Cl. & Grun.
	Nitzschia acuta	Hantz.
	Nitzschia amphibia	Grun.
	Nitzschia angustata	(W. Sm.) Grun.
	Nitzschia angustata v. acuta	Grun.
	Nitzschia bacata	Hust.
	Nitzschia capitellata	Hust.
	Nitzschia confinis	Hust.
	Nitzschia confinis?	Hust.
	Nitzschia dissipata	(Kutz.) Grun.
	Nitzschia fonticola	Grun.

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Nitzschia frustulum</i>	(Kutz.) Grun.
	<i>Nitzschia frustulum</i> v. <i>minutula</i>	
	<i>Nitzschia gandersheimiensis</i>	Krasske
	<i>Nitzschia gracilis</i>	Hantz.
	<i>Nitzschia impressa</i>	Hust.
	<i>Nitzschia kuetzingiana</i>	Hilse
	<i>Nitzschia lauerburgiana</i>	Hust.
	<i>Nitzschia linearis</i>	W. Sm.
	<i>Nitzschia palea</i>	(Kutz.) W. Sm.
	<i>Nitzschia palea</i> v. <i>debilis</i>	(Kutz.) Grun.
	<i>Nitzschia paleacea</i>	Grun.
	<i>Nitzschia pura?</i>	Hust.
	<i>Nitzschia recta</i>	Hantz.
	<i>Nitzschia romana</i>	Grun.
	<i>Nitzschia sociabilis</i>	Hust.
	<i>Nitzschia</i> sp.	
	<i>Nitzschia spiculum</i>	Hust.
	<i>Nitzschia subacicularis</i>	Hust.
	<i>Nitzschia sublinearis</i>	Hust.
	<i>Nitzschia sublinearis?</i>	Hust.
	<i>Nitzschia subrostrata</i>	Hust.
	<i>Nitzschia tenuis</i>	W. Sm.
	<i>Nitzschia valdestrita</i>	Aleem & Hust.
	<i>Opephora martyi</i>	Herib.
	<i>Rhizosolenia eriensis</i>	H.L. Sm.
	<i>Rhizosolenia longiseta</i>	Zach.
	<i>Rhizosolenia</i> sp.	
	<i>Rhoiocosphenia curvata</i>	(Kutz.) Grun.
	<i>Skeletonema pectus</i>	(Weber) Hasle & Evens.
	<i>Stauroneis smithii</i> v. <i>minuta</i>	Haw.
	<i>Stephanodiscus alpinus</i>	Hust.
	<i>Stephanodiscus alpinus?</i>	Hust.
	<i>Stephanodiscus binderanus</i>	(Kutz.) Krieg.
	<i>Stephanodiscus binderanus?</i>	(Kutz.) Krieg.
	<i>Stephanodiscus hantzschii</i>	Grun.
	<i>Stephanodiscus minutus</i>	Grun.
	<i>Stephanodiscus niagarae</i>	Ehr.
	<i>Stephanodiscus</i> sp.	
	<i>Stephanodiscus</i> sp. #03	
	<i>Stephanodiscus</i> sp. -auxospore	
	<i>Stephanodiscus subtilis</i>	(Van Goor) A. Cl.
	<i>Stephanodiscus tenuis</i>	Hust.
	<i>Stephanodiscus tenuis</i> v. #01	
	<i>Stephanodiscus tenuis</i> v. #02	
	<i>Stephanodiscus tenuis?</i>	Hust.
	<i>Stephanodiscus transilvanicus</i>	Pant.
	<i>Surirella angusta</i>	Kutz.
	<i>Synedra amphicephala</i> v. <i>austriaca</i>	(Grun.) Hust.
	<i>Synedra cyclopum</i>	Brutschy
	<i>Synedra delicatissima</i> v. <i>angustissima</i>	Grun.
	<i>Synedra famellica</i>	Kutz.
	<i>Synedra filiformis</i>	Grun.

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Synedra filiformis</i> v. <i>exilis</i>	A. Cl.
	<i>Synedra miniscula</i>	Grun.
	<i>Synedra parasitica</i>	W. Sm.
	<i>Synedra radians</i>	Kutz.
	<i>Synedra</i> sp.	
	<i>Synedra ulna</i>	(Nitz.) Ehr.
	<i>Synedra ulna</i> v. <i>chaseana</i>	Thomas
	<i>Synedra ulna</i> v. <i>danica</i>	(Kutz.) V.H.
	<i>Synedra ulna</i> v. <i>longissima</i>	(W. Sm.) Brun.
	<i>Tabellaria ferestrata</i>	Kutz.
	<i>Tabellaria ferestrata</i> v. <i>geniculata</i>	A. Cl.
	<i>Tabellaria flocculosa</i>	(Roth) Kutz.
	<i>Tabellaria flocculosa</i> v. <i>linearis</i>	Koppen
CAT	<i>Vacuolaria</i> sp.	
CHL	<i>Ankistrodesmus falcatus</i>	(Corda) Ralfs
	<i>Ankistrodesmus gelifactum</i>	(Chod.) Bourr.
	<i>Ankistrodesmus</i> sp. #01	
	<i>Ankistrodesmus</i> sp.?	
	<i>Arthrodesmus bifidus</i>	Breb.
	<i>Botryococcus Braunii</i>	Kutz.
	<i>Carteria</i> sp.	
	<i>Chlamydocapsa planktonica</i>	(W. & G.S. West) Fott
	<i>Chlamydocapsa</i> sp.	
	<i>Chlamydomonas</i> sp.	
	<i>Chlamydomonas</i> sp. - ovoid	
	<i>Chlamydomonas</i> sp. - sphere	
	<i>Closteriopsis</i> sp.	
	<i>Closterium aciculare</i>	T. West
	<i>Closterium gracile</i>	Breb.
	<i>Coelastrum carbricum</i>	Arch.
	<i>Coelastrum microporum</i>	Nag. in A. Braun
	<i>Coelastrum</i> sp.	
	<i>Coenocystis</i> sp.	
	<i>Cosmarium</i> sp.	
	<i>Crucigenia irregularis</i>	Wille
	<i>Crucigenia quadrata</i>	Morren
	<i>Crucigenia rectangularis</i>	A. Braun
	<i>Dictyosphaerium ehrenbergianum</i>	Nag.
	<i>Dictyosphaerium pulchellum</i>	Wood.
	<i>Elakatothrix gelatinosa</i>	Wille
	<i>Elakatothrix viridis</i>	(Snow) Printz
	<i>Elakatothrix viridis?</i>	(Snow) Printz
	<i>Gloedactinium linneticum</i>	G.M. Sm.
	<i>Golenkinopsis</i> sp.	
	Green coccoid	
	Green coccoid #04	
	Green coccoid - acicular	
	Green coccoid - bacilliiform	
	Green coccoid - bicells	
	Green coccoid - fusiform	

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHL	Green coccoid - fusiform bicells	
	Green coccoid - oocystis-like bicell	
	Green coccoid - oval	
	Green coccoid - reniform	
	Green coccoid - sphere	
	Green coccoid - sphere (large)	
	Kirchneriella contorta	(Schmid.) Bohlm
	Monoraphidium contortum	(Thur.) Kom.-Legn.
	Monoraphidium irregulare	(G.M. Sm.) Kom.-Legn.
	Monoraphidium minutum	(Nag.) Kom.-Legn.
	Monoraphidium saxatile	Kom.-Legn.
	Monoraphidium setiformae	(Nyg.) Kom.-Legn.
	Monoraphidium tortile	(W. & W.) Kom.-Legn.
	Nephrocytium Agardhianum	Nag.
	Nephrocytium limneticum	(G.M. Sm.) G.M. Sm.
	Gedogonium sp.	
	Oocystis sp.	
	Oocystis sp. #1	
	Oocystis borgei	Snow
	Oocystis crassa	Wittr. in Wittr. & Nord.
	Oocystis lacustris	Chod.
	Oocystis marscnii	Lemm.
	Oocystis parva	West & West
	Oocystis pusilla	Hansg.
	Oocystis solitaria	Wittr. in Wittr. & Nord.
	Oocystis submarina	Lagerh.
	Pediastrum sp.?	
	Phacotus minuscula	Bourr.
	Phacotus sp.	
	Planktonema lauterbornii	Schmidle
	Planktonema sp.	
	Pteromonas sp.	
	Pyramidomonas sp.	
	Scenedesmus acuminatus	(Lagerh.) Chod.
	Scenedesmus eccentricus	(Ralfs) Chod.
	Scenedesmus quadricauda	(Turp.) Breb.
	Scenedesmus quadricauda v. longispina	(Chod.) G.M. Sm.
	Scenedesmus securiformis	Playf.
	Scenedesmus serratus	(Corda) Bohlm
	Scenedesmus sp.	
	Scenedesmus spinosus	Chod.
	Schroederia setigera	(Schroed.) Lemm.
	Sphaerello cystis lacustris	Skuja
	Sphaerello cystis lateralis	Fott & Novak.
	Sphaerocystis schroeteri	Chod.
	Stichococcus sp.	
	Tetraedron caudatum	(Corda) Hansg.
	Tetraedron minimum	(A. Braun) Hansg.
	Tetraspora lacustris	Lemm.
	Tetrastrum glabrum	
	Treubaria planktonica	(G.M. Sm.) Korch.
	Treubaria setigera	(Arch.) G.M. Sm.

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHR	<i>Bitrichia chodatii</i>	(Rev.) Chod.
	<i>Bitrichia ohridiana</i>	(Fott) Nich.
	<i>Chromulina</i> sp.	
	<i>Chrysococcus</i> sp.?	
	<i>Chrysolykos angulatus</i>	(Willen) Nauw.
	<i>Chrysolykos planktonicus</i>	Mack.
	<i>Chrysolykos skuja</i>	(Nauw.) Bourr.
	<i>Chrysolykos</i> sp.	
	<i>Chrysosphaerella longispina</i>	Laut. em. Nich.
	<i>Dinobryon</i> - cyst	
	<i>Dinobryon acuminatum</i>	Rutt.
	<i>Dinobryon bavaricum</i>	Imhof
	<i>Dinobryon borgei</i>	Lemm.
	<i>Dinobryon cylinoricum</i>	Imhof
	<i>Dinobryon divergens</i>	Imhof
	<i>Dinobryon eurystoma?</i>	(Stokes) Lemm.
	<i>Dinobryon sertularia</i>	Ehr.
	<i>Dinobryon sociale</i>	Ehr.
	<i>Dinobryon sociale</i> v. <i>americanum</i>	(Brunnth.) Bachm.
	<i>Dinobryon sociale</i> v. <i>stiptatum</i>	(Stein) Lemm.
	<i>Dinobryon</i> sp.	
	<i>Dinobryon stokesii</i> v. <i>epiplanktonicum</i>	Skuja
	<i>Dinobryon tubaeformae</i>	Nyg.
	<i>Dinobryon utriculus</i> v. <i>tabellariae</i>	Lemm.
	<i>Halobryon</i> sp.?	
	<i>Haptophyte</i> sp.	
	<i>Kephyrion cupuliformae</i>	Conr.
	<i>Kephyrion doliolum</i>	Conr.
	<i>Kephyrion rubi-calustri</i>	Conr.
	<i>Kephyrion</i> sp.	
	<i>Kephyrion</i> sp. #1 - <i>Pseudokephyrion entzii</i>	
	<i>Kephyrion</i> sp. #2	
	<i>Kephyrion</i> sp. #3	
	<i>Kephyrion spirale</i>	(Lack.) Conr.
	<i>Mallomonas majorensis</i>	Skuja
	<i>Mallomonas</i> sp.	
	<i>Mallomonas</i> sp. #3	
	<i>Ochromonas</i> sp.	
	<i>Ochromonas</i> sp. - oval	
	<i>Ochromonas</i> sp. - ovoid	
	<i>Ochromonas</i> sp. - sphere	
	<i>Paraphysomonas</i> sp.	
	<i>Paraphysomonas</i> sp.?	
	<i>Pseudokephyrion conicum</i>	(Schill.) Schum.
	<i>Pseudokephyrion latum</i>	(Schill.) Schum.
	<i>Pseudokephyrion millerense</i>	Nich.
	<i>Pseudokephyrion</i> sp. #1	
	<i>Pseudokephyrion undulatisimum</i>	Scherff.
	Unidentified coccoid - ovoid	
	Unidentified coccoid - sphere	
	Unidentified coccoids	
	Unidentified loricate - sphere	

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHR	Unidentified loricate-flagellate sphere	
COL	Bicoeca campanulata	(Lack.) Bourr. em. Skuja
	Bicoeca lacustris?	J. Clark
	Bicoeca mitra v.?	
	Bicoeca sp.	
	Bicoeca sp. #04	
	Bicoeca tubiformis	Skuja
	Codonosiga sp.	
	Colorless flagellate - ovoid	
	Colorless flagellate - sphere	
	Colorless flagellates	
	Mastigella sp.	
	Monosiga ovata	Kent
	Salpingoeca amphorae	Kent
	Salpingoeca gracilis	Clark
	Salpingoeca sp.	
	Stylothea aurea	(Bachm.) Boloch.
CRY	Chroomonas acuta	Uterm.
	Chroomonas caudata	Geit.
	Chroomonas norstedtii	Hansg.
	Chroomonas pochmanni	Huber-Pest.
	Cryptomonas - cyst	
	Cryptomonas brevis	Schill.
	Cryptomonas brevis?	Schill.
	Cryptomonas caudata	Schill.
	Cryptomonas ercsa	Ehr.
	Cryptomonas ercsa v. reflexa	Marss.
	Cryptomonas lobata	Korsch.
	Cryptomonas marssonii	Skuja
	Cryptomonas marssonii v.?	Skuja
	Cryptomonas ovata	Ehr.
	Cryptomonas parapyrenoidifera	Skuja
	Cryptomonas phaseolus	Skuja
	Cryptomonas pusilla	Bachm.
	Cryptomonas pyrenoidifera	Geitl.
	Cryptomonas reflexa v. erosa	
	Cryptomonas rostratiformis	Skuja
	Cryptomonas sp.	
	Cryptomonas tenuis	Pasch.
	Cryptomonas tetrapyreniodiosa	Skuja
	Rhodomonas lacustris	Pasch. & Rutt.
	Rhodomonas lens	Pasch. & Rutt.
	Rhodomonas minuta	Skuja
	Rhodomonas minuta v. nannoplanktica	Skuja
	Sennia parvula	Skuja
	Sennia parvula?	Skuja
CYA	Anabaena flos-aquae	(Lyngb.) Breb.
	Anabaena sp.	
	Anacystis marina	(Hansg.) Dr. & Daily

## SPECIES LIST - LAKE MICHIGAN PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CYA	Anacystis montana	Dr. & Daily
	Anacystis montana v. minor	Dr. & Daily
	Anacystis thermalis	(Menegh.) Dr. & Daily
	Aphanothece gelatinosa	(Henn.) Lemm.
	Coccochloris elabans	Dr. & Daily
	Coccochloris penlocystis	(Kutz.) Dr. & Daily
	Coelosphaerium naegelianum	Unger
	Dactylococcopsis Smithii	Chod. & Chod.
	Dactylococcopsis sp.	
	Gloeotheca ruprestis	(Lyngb.) Born.
	Gomphosphaeria lacustris	Chod.
	Lyngbya limneticum	Lemm.
	Oscillatoria agardhii	Gom.
	Oscillatoria limnetica	Lemm.
	Oscillatoria limnetica?	Lemm.
	Oscillatoria minima	Gicklth.
	Oscillatoria sp.	
	Oscillatoria subbrevis	Schmid.
	Oscillatoria tenuis	C.A. Ag.
	Oscillatoria tenuis v. natans	Gom.
	Oscillatoria tenuis v. tergistina	(Kutz.) Rabh.
	Unidentified blue-greens	
EUG	Euglena sp.	
PYR	Amphidinium sp.	
	Ceratium hirundinella	(O.F.Mull.) Schrank
	Dinoflagellate cyst	
	Gymnodinium sp.	
	Gymnodinium sp. #1	
	Gymnodinium sp. #2	
	Gymnodinium sp. #3	
	Peridinium cinctum	(Mull.) Ehr.
	Peridinium inconspicuum	Lemm.
	Peridinium sp.	
UNI	Unidentified coccoid flagellates	
	Unidentified flagellate #01	
	Unidentified flagellate #03	
	Unidentified flagellate - ovoid	
	Unidentified flagellate - spherical	



## Table B.

Phytoplankton  
Species List: Lake Huron

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Achnanthes affinis</i>	Grun.
	<i>Achnanthes biasolettiana</i>	(Kutz.) Grun.
	<i>Achnanthes brevipes</i> v. <i>intermedia</i>	(Kutz.) Cl.
	<i>Achnanthes clevei</i>	Grun.
	<i>Achnanthes clevei</i> v. <i>rostrata</i>	Hust.
	<i>Achnanthes conspicua</i> ?	A. Mayer
	<i>Achnanthes oetha</i>	Hohn & Hellerm.
	<i>Achnanthes exigua</i>	Grun.
	<i>Achnanthes exigua</i> v. <i>heterovalva</i>	Krasske
	<i>Achnanthes flexella</i>	(Kutz.) Brun.
	<i>Achnanthes hauckiana</i>	Grun.
	<i>Achnanthes lanceolata</i>	(Breb.) Greg.
	<i>Achnanthes lanceolata</i> v. <i>dubia</i>	Grun.
	<i>Achnanthes lapponica</i> v. <i>ninckei</i>	(Guerm. & Mang.) Reim.
	<i>Achnanthes laterostrata</i>	Hust.
	<i>Achnanthes linearis</i>	(W. Sm.) Grun.
	<i>Achnanthes linearis</i> fo. <i>curta</i>	H.L. Sm.
	<i>Achnanthes marginulata</i>	Grun.
	<i>Achnanthes microcephala</i>	(Kutz.) Grun.
	<i>Achnanthes minutissima</i>	Kutz.
	<i>Achnanthes</i> sp.	
	<i>Amphipleura pellucida</i>	(Kutz.) Kutz.
	<i>Amphora coffeiformis</i>	(Ag.) Kutz.
	<i>Amphora inariensis</i>	Kram.
	<i>Amphora ovalis</i>	(Kutz.) Kutz.
	<i>Amphora ovalis</i> v. <i>pediculus</i>	(Kutz.) V.H. ex DeT.
	<i>Amphora perpusilla</i>	(Grun.) Grun.
	<i>Amphora</i> sp.	
	<i>Anomoeoneis vitrea</i>	(Grun.) Patr. & Reim.
	<i>Asterionella formosa</i>	Hass.
	<i>Asterionella formosa</i> v. <i>gracillima</i>	(Hantz.) Grun
	<i>Caloneis bacillum</i>	(Grun.) Cl.
	<i>Cocconeis diminuta</i>	Pant.
	<i>Cocconeis disculus</i>	(Schum.) Cl.
	<i>Cocconeis placentula</i> v. <i>euglypta</i>	(Ehr.) Cl.
	<i>Cocconeis placentula</i> v. <i>lineata</i>	(Ehr.) Cl.
	<i>Cyclostephanos dubius</i>	(Fricke) Round
	<i>Cyclotella antiqua</i> ?	W. Sm.
	<i>Cyclotella catenata</i>	Brun.
	<i>Cyclotella comensis</i>	Grun.
	<i>Cyclotella comensis</i> - auxospore	
	<i>Cyclotella comensis</i> v. 1	
	<i>Cyclotella comensis</i> v. 2	
	<i>Cyclotella comta</i>	(Ehr.) Kutz.
	<i>Cyclotella comta</i> - auxospore	
	<i>Cyclotella comta</i> v. #2	
	<i>Cyclotella comta</i> v. <i>oligactis</i>	(Ehr.) Grun.
	<i>Cyclotella cryptica</i>	Reim. et al.
	<i>Cyclotella kuetzingiana</i>	Thw.
	<i>Cyclotella kuetzingiana</i> v. <i>planetophora</i>	Fricke
	<i>Cyclotella kuetzingiana</i> v. <i>planetophora</i> ?	Fricke
	<i>Cyclotella kuetzingiana</i> v. <i>radiosa</i>	Fricke

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Cyclotella meneghiniana</i>	Kutz.
	<i>Cyclotella michiganiana</i>	Skv.
	<i>Cyclotella ocellata</i>	Pant.
	<i>Cyclotella operculata</i>	(Ag.) Kutz.
	<i>Cyclotella pseudostelligera</i>	Hust.
	<i>Cyclotella</i> sp.	
	<i>Cyclotella</i> sp. #1	
	<i>Cyclotella</i> sp. #2	
	<i>Cyclotella</i> sp. - auxospore	
	<i>Cyclotella stelligera</i>	(Cl. & Grun.) V.H.
	<i>Cymatopleura solea</i> v. <i>apiculata</i>	(W. Sm.) Ralfs
	<i>Cymbella angustata</i>	(W. Sm.) Cl.
	<i>Cymbella laevis</i>	Naeg. ex Kutz.
	<i>Cymbella microcephala</i>	Grun.
	<i>Cymbella minuta</i>	Hilse
	<i>Cymbella minuta</i> v. <i>silesiaca</i>	(Bleisch) Reim.
	<i>Cymbella naviculiformis</i>	Auersw.
	<i>Cymbella</i> sp.	
	<i>Cymbella triangulum</i>	(Ehr.) Cl.
	<i>Denticula</i> sp.	
	<i>Denticula tenuis</i> v. <i>crassula</i>	(Nag.) W. & G.S. West.
	<i>Diatoma tenue</i>	Ag.
	<i>Diatoma tenue</i> v. <i>elongatum</i>	Lyngb.
	<i>Diploneis elliptica</i>	(Kutz.) Cl.
	<i>Diploneis oolongella</i>	(Naeg. ex Kutz.) Ross
	<i>Diploneis oculata</i>	(Breb.) Cl.
	<i>Entomoneis ornata</i>	(J.W. Bail.) Reim.
	<i>Eunotia praerupta</i>	Ehr.
	<i>Fragilaria brevistriata</i>	Grun.
	<i>Fragilaria brevistriata</i> v. <i>subcapitata</i>	Grun.
	<i>Fragilaria capucina</i>	Desm.
	<i>Fragilaria capucina</i> v. <i>mesolepta</i>	(Rabh.) Grun.
	<i>Fragilaria construens</i>	(Ehr.) Grun.
	<i>Fragilaria construens</i> v. <i>minuta</i>	Temp. & Per.
	<i>Fragilaria construens</i> v. <i>pumila</i>	Grun.
	<i>Fragilaria construens</i> v. <i>subsalina</i>	Hust.
	<i>Fragilaria construens</i> v. <i>venter</i>	(Ehr.) Grun.
	<i>Fragilaria crotonensis</i>	Kitton
	<i>Fragilaria intermedia</i> v. <i>fallax</i>	(Grun.) Stoerm. & Yang
	<i>Fragilaria leptostauron</i>	(Ehr.) Hust.
	<i>Fragilaria leptostauron</i> v. <i>dubia</i>	(Grun.) Hust.
	<i>Fragilaria pinnata</i>	Ehr.
	<i>Fragilaria pinnata</i> v. <i>intercedens</i>	(Grun.) Hust.
	<i>Fragilaria pinnata</i> v. <i>lancettula</i>	(Schum.) Hust.
	<i>Fragilaria</i> sp.	
	<i>Fragilaria vaucheriae</i>	(Kutz.) Peters.
	<i>Gomphonema angustatum</i>	(Kutz.) Rabh.
	<i>Gomphonema dichotomum</i>	Kutz.
	<i>Gomphonema gracile</i>	Ehr. em. V.H.
	<i>Gomphonema olivaceum</i>	(Lyngb.) Kutz.
	<i>Gomphonema parvulum</i>	Kutz.
	<i>Gomphonema</i> sp.	

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Hantzschia amphioxys</i>	(Ehr.) Grun.
	<i>Melosira distans</i>	(Ehr.) Kutz.
	<i>Melosira distans?</i>	(Ehr.) Kutz.
	<i>Melosira granulata</i>	(Ehr.) Ralfs
	<i>Melosira granulata</i> v. <i>angustissima</i>	O. Mull.
	<i>Melosira islandica</i>	O. Mull.
	<i>Melosira italica</i> subsp. <i>subarctica</i>	O. Mull.
	<i>Melosira</i> sp.	
	<i>Navicula acceptata</i>	Hust.
	<i>Navicula atomus</i>	(Kutz.) Grun.
	<i>Navicula capitata</i> v. <i>luneburgensis</i>	(Grun.) Patr.
	<i>Navicula cincta</i>	(Ehr.) Ralfs
	<i>Navicula confervacea</i>	Kutz.
	<i>Navicula contera</i> v. <i>biceps</i>	(Arn.) V.H.
	<i>Navicula cryptocephala</i> v. <i>veneta</i>	(Kutz.) Rabh.
	<i>Navicula gottlandica</i>	Grun.
	<i>Navicula medicris</i>	Krasske
	<i>Navicula minima</i>	Grun.
	<i>Navicula muralis</i>	Grun.
	<i>Navicula muralis?</i>	Grun.
	<i>Navicula mutica</i>	Kutz.
	<i>Navicula perpusilla</i>	(Kutz.) Grun.
	<i>Navicula radiosa</i>	Kutz.
	<i>Navicula radiosa</i> v. <i>parva</i>	Wallace
	<i>Navicula radiosa</i> v. <i>tenella</i>	(Breb.) Cl. & Moll.
	<i>Navicula seminulum</i>	Grun.
	<i>Navicula similis?</i>	Krasske
	<i>Navicula</i> sp.	
	<i>Navicula</i> sp. #16	
	<i>Navicula</i> sp. #18	
	<i>Navicula submuralis</i>	Hust.
	<i>Navicula subtilissima</i>	Cl.
	<i>Navicula tantula</i>	Hust.
	<i>Navicula viridula</i> v. <i>avenacea</i>	(Breb.) V.H.
	<i>Navicula viridula</i> v. <i>rostellata?</i>	(Kutz.) Cl.
	<i>Nitzschia acicularioides</i>	Arch. non Hust.
	<i>Nitzschia acicularis</i>	(Kutz.) W. Sm.
	<i>Nitzschia acula</i>	Hantz. ex Cl. & Grun.
	<i>Nitzschia amphibia</i>	Grun.
	<i>Nitzschia angustata</i>	(W. Sm.) Grun.
	<i>Nitzschia angustata</i> v. <i>acuta</i>	Grun.
	<i>Nitzschia confinis</i>	Hust.
	<i>Nitzschia dissipata</i>	(Kutz.) Grun.
	<i>Nitzschia fonticola</i>	Grun.
	<i>Nitzschia frustulum</i>	(Kutz.) Grun.
	<i>Nitzschia frustulum</i> v. <i>perpusilla</i>	(Rabh.) Grun.
	<i>Nitzschia gracilis</i>	Hantz.
	<i>Nitzschia kuetzingiana</i>	Hilse
	<i>Nitzschia lauenburgiana</i>	Hust.
	<i>Nitzschia palea</i>	(Kutz.) W. Sm.
	<i>Nitzschia paleacea</i>	Grun.
	<i>Nitzschia pura</i>	Hust.

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Nitzschia pusilla</i>	(Kutz.) Grun. em. L.-B.
	<i>Nitzschia recta</i>	Hantz.
	<i>Nitzschia romana</i>	Grun.
	<i>Nitzschia rostellata</i>	Hust.
	<i>Nitzschia</i> sp.	
	<i>Nitzschia sublinearis</i>	Hust.
	<i>Nitzschia subrostrata</i>	Hust.
	<i>Nitzschia tenuis</i>	W. Sm.
	<i>Opephora martyi</i>	Herib.
	<i>Pinnularia microstauron</i>	(Ehr.) Cl.
	<i>Rhizosolenia eriensis</i>	H.L. Sm.
	<i>Rhizosolenia</i> sp.	
	<i>Stephanodiscus alpinus</i>	Hust.
	<i>Stephanodiscus alpinus</i> - auxospore	
	<i>Stephanodiscus alpinus?</i>	Hust.
	<i>Stephanodiscus binderanus</i>	(Kutz.) Krieg.
	<i>Stephanodiscus binderanus?</i>	(Kutz.) Krieg.
	<i>Stephanodiscus hantzschii</i>	Grun.
	<i>Stephanodiscus minutus</i>	Grun.
	<i>Stephanodiscus niagarae</i>	Ehr.
	<i>Stephanodiscus niagarae</i> - auxospore	
	<i>Stephanodiscus</i> sp.	
	<i>Stephanodiscus</i> sp. #03	
	<i>Stephanodiscus</i> sp. #05	
	<i>Stephanodiscus</i> sp. -auxospore	
	<i>Stephanodiscus tenuis</i>	Hust.
	<i>Stephanodiscus tenuis</i> v. #01	
	<i>Stephanodiscus tenuis</i> v. #02	
	<i>Stephanodiscus tenuis?</i>	Hust.
	<i>Stephanodiscus transilvanicus</i>	Pant.
	<i>Surirella ovata</i>	Kutz.
	<i>Surirella ovata</i> v. <i>salina</i>	(W. Sm.) Hust.
	<i>Synedra amphicephala</i> v. <i>austriaca</i>	(Grun.) Hust.
	<i>Synedra cyclopus</i>	Brutschy
	<i>Synedra delicatissima</i>	W. Sm.
	<i>Synedra delicatissima</i> v. <i>angustissima</i>	Grun.
	<i>Synedra famellica?</i>	Kutz.
	<i>Synedra filiformis</i>	Grun.
	<i>Synedra filiformis</i> v. <i>exilis</i>	A. Cl.
	<i>Synedra miniscula</i>	Grun.
	<i>Synedra nana</i>	Meister
	<i>Synedra parasitica</i>	W. Sm.
	<i>Synedra radians</i>	Kutz.
	<i>Synedra rumpens</i>	Kutz.
	<i>Synedra rumpens</i> v. <i>fragilarioides</i>	Grun.
	<i>Synedra</i> sp.	
	<i>Synedra ulna</i> v. <i>chaseana</i>	Thomas
	<i>Synedra ulna</i> v. <i>danica</i>	(Kutz.) V.H.
	<i>Synedra ulna</i> v. <i>longissima</i>	(W. Sm.) Brun.
	<i>Tabellaria ferestrata</i>	Kutz.
	<i>Tabellaria fenestrata</i> v. <i>geniculata</i>	A. Cl.
	<i>Tabellaria flocculosa</i>	(Roth) Kutz.

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

[illegible]

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHL	<i>Monoraphidium setiformae</i>	(Nyg.) Kom.-Legn.
	<i>Mougeotia</i> sp.	
	<i>Oocystis</i> sp.	
	<i>Oocystis</i> sp. #1	
	<i>Oocystis</i> Borgei	Snow
	<i>Oocystis</i> crassa	Wittr. in Wittr. & Nord.
	<i>Oocystis</i> lacustris	Chod.
	<i>Oocystis</i> marschii	Lemm.
	<i>Oocystis</i> parva	West & West
	<i>Oocystis</i> pusilla	Hansg.
	<i>Oocystis</i> solitaria	Wittr. in Wittr. & Nord.
	<i>Pyramidomonas</i> sp.	
	<i>Scenedesmus</i> abundans	(Kirch.) Chod.
	<i>Scenedesmus</i> denticulatus	Lagerh.
	<i>Scenedesmus</i> eornis	(Ralfs) Chod.
	<i>Scenedesmus</i> securiformis	Playf.
	<i>Scenedesmus</i> securiformis?	Playf.
	<i>Scenedesmus</i> serratus	(Corda) Bohlm
	<i>Scenedesmus</i> sp.	
	<i>Scenedesmus</i> subspicatus	Chod.
	<i>Scenedesmus</i> velitaris	Kom.
	<i>Sphaerello cystis</i> lateralis	Fott & Novak.
	<i>Sphaerocystis</i> schroeteri	Chod.
	<i>Stichococcus</i> sp.	
	<i>Synechococcus</i> sp.	
	<i>Tetrachlorella</i> alternans	(G.M. Smith) Kors.
	<i>Tetraedron</i> minimum	(A. Braun) Hansg.
	<i>Treubaria</i> planktonica	(G.M. Sm.) Korch.
	<i>Treubaria</i> planktonica?	(G.M. Sm.) Korch.
	<i>Treubaria</i> setigera	(Arch.) G.M. Sm.
CHR	<i>Bitrichia</i> chodatii	(Rev.) Chod.
	<i>Chrysolykos</i> planktonicus	Mack.
	<i>Chrysolykos</i> skujae	(Nauw.) Bourr.
	<i>Chrysolykos</i> sp.	
	<i>Chrysosphaerella</i> longispina	Laut. em. Nich.
	<i>Dinobryon</i> - statospore	
	<i>Dinobryon</i> acuminatum	Rutt.
	<i>Dinobryon</i> bavaricum	Imhof
	<i>Dinobryon</i> borgei	Lemm.
	<i>Dinobryon</i> cylindricum	Imhof
	<i>Dinobryon</i> cylindricum v. alpinum	(Imhof) Bachm.
	<i>Dinobryon</i> divergens	Imhof
	<i>Dinobryon</i> divergens - statospores	
	<i>Dinobryon</i> eurytoma	(Stokes) Lemm.
	<i>Dinobryon</i> sertularia	Ehr.
	<i>Dinobryon</i> sertularia v. protuberans	(Lemm.) Krieg.
	<i>Dinobryon</i> sociale	Ehr.
	<i>Dinobryon</i> sociale v. americanum	(Brunnth.) Bachm.
	<i>Dinobryon</i> stokesii v. epiplanktonicum	Skuja
	<i>Dinobryon</i> utriculus v. tabellariae	Lemm.
	<i>Haptophyte</i> sp.	

## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHR	Kephyrion cupuliformae	Conr.
	Kephyrion sp. #1 -Pseudokephyrion entzii	
	Kephyrion sp. #2	
	Kephyrion sp. #3	
	Kephyrion spirale	(Lack.) Conr.
	Mallomonas sp.	
	Mallomonas sp. #1	
	Mallomonas sp. #3	
	Ochromonas sp.	
	Ochromonas sp. - ovoid	
	Ochromonas sp. - sphere	
	Paraphysomonas sp.	
	Paraphysomonas sp.?	
	Pseudokephyrion entzii	Conr.
	Pseudokephyrion conicum	(Schill.) Schum.
	Pseudokephyrion latum	(Schill.) Schum.
	Pseudokephyrion millerense	Nich.
	Pseudokephyrion sp. #1	
	Unidentified coccoids	
	Unidentified loricate - ovoid	
	Unidentified loricate - sphere	
CDL	Bicoeca campanulata	(Lack.) Bourr. em. Skuja
	Bicoeca crystallina	Skuja
	Bicoeca mitra v. suecica	Skuja
	Bicoeca socialis	Lauterb.
	Bicoeca sp.	
	Bicoeca sp. #04	
	Bicoeca tubiformis	Skuja
	Colorless flagellates	
	Monosiga ovata	Kent
	Monosigna ovalis	Kent
	Salpingoeca amphorae	Kent
	Salpingoeca gracilis	Clark
	Stylothea aurea	(Bachm.) Boloch.
CRY	Chroomonas acuta	Uterm.
	Chroomonas caudata	Gelt.
	Chroomonas norstedtii	Hansg.
	Cryptomonas - cyst	
	Cryptomonas brevis	Schill.
	Cryptomonas caudata	Schill.
	Cryptomonas ercsa	Ehr.
	Cryptomonas ercsa v. reflexa	Marss.
	Cryptomonas marssonii	Skuja
	Cryptomonas obovata?	Skuja
	Cryptomonas ovata	Ehr.
	Cryptomonas parapyrenoidifera	Skuja
	Cryptomonas phaseolus	Skuja
	Cryptomonas phaseolus?	Skuja
	Cryptomonas pusilla	Bachm.
	Cryptomonas pyrenoidifera	Gelt.



## SPECIES LIST - LAKE HURON PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CRY	<i>Cryptomonas reflexa</i>	Skuja
	<i>Cryptomonas rostratiformis</i>	Skuja
	<i>Cryptomonas</i> sp.	
	<i>Cryptomonas tenuis</i>	Pasch.
	<i>Cryptomonas tetrapyrenoidiosa?</i>	Skuja
	<i>Rhodomonas lacustris</i>	Pasch. & Rutt.
	<i>Rhodomonas lens</i>	Pasch. & Rutt.
	<i>Rhodomonas minuta</i>	Skuja
	<i>Rhodomonas minuta</i> v. <i>nannoplanktica</i>	Skuja
	Unidentified coccoid	
CYA	<i>Anabaena circinalis</i>	Rabenhorst
	<i>Anabaena</i> sp.	
	<i>Anacystis marina</i>	(Hansg.) Dr. & Daily
	<i>Anacystis montana</i> v. <i>minor</i>	Dr. & Daily
	<i>Anacystis thermalis</i>	(Menegh.) Dr. & Daily
	<i>Coccochloris elabans</i>	Dr. & Daily
	<i>Coccochloris peniocyctis</i>	(Kutz.) Dr. & Daily
	<i>Coelosphaerium Naegelianum</i>	Unger
	<i>Gomphosphaeria lacustris</i>	Chod.
	<i>Oscillatoria limnetica</i>	Lemm.
	<i>Oscillatoria minima</i>	Gicklh.
	<i>Oscillatoria subbrevis</i>	Schmid.
	<i>Oscillatoria tenuis</i>	C.A. Ag.
EUG	<i>Euglena</i> sp.	
	<i>Phacus</i> sp.	
	<i>Trachelomonas hispida</i>	(Perty) Stein em. Defl.
	<i>Trachelomonas</i> sp.	
PYR	<i>Amphidinium</i> sp.	
	<i>Ceratium hirundinella</i>	(O.F.Mull.) Schrank
	<i>Gymnodinium</i> sp.	
	<i>Gymnodinium</i> sp. #1	
	<i>Gymnodinium</i> sp. #2	
	<i>Gymnodinium</i> sp. #3	
	<i>Gymnodinium</i> sp. #5	
	<i>Peridinium inconspicuum</i>	Lemm.
	<i>Peridinium</i> sp.	
	<i>Peridinium</i> sp. #02	
UNI	Unidentified flagellate #01	
	Unidentified flagellate - ovoid	
	Unidentified flagellate - spherical	

## Table C

Phytoplankton  
Species List: Lake Erie

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Achnanthes biasolettiana</i>	(Kutz.) Grun.
	<i>Achnanthes bioreti</i>	Germ.
	<i>Achnanthes clevei</i>	Grun.
	<i>Achnanthes clevei</i> v. <i>rostrata</i>	Hust.
	<i>Achnanthes conspicua</i>	A. Mayer
	<i>Achnanthes exigua</i>	Grun.
	<i>Achnanthes hauckiana</i>	Grun.
	<i>Achnanthes lanceolata</i> v. <i>dubia</i>	Grun.
	<i>Achnanthes lemmermanni</i>	Hust.
	<i>Achnanthes linearis</i>	(W. Sm.) Grun.
	<i>Achnanthes linearis</i> fo. <i>curta</i>	H.L. Sm.
	<i>Achnanthes microcephala</i>	(Kutz.) Grun.
	<i>Achnanthes minutissima</i>	Kutz.
	<i>Achnanthes</i> sp.	
	<i>Achnanthes</i> sp.?	
	<i>Achnanthes sublaevis</i>	Hust.
	<i>Actinocyclus normanii</i> f. <i>subsalsus</i>	(Juhl.-Dannf.) Hust.
	<i>Actinocyclus</i> sp.	
	<i>Amphora ovalis</i> v. <i>affinis</i>	(Kutz.) V.H. ex DeT.
	<i>Amphora ovalis</i> v. <i>pediculus</i>	(Kutz.) V.H. ex DeT.
	<i>Amphora perpusilla</i>	(Grun.) Grun.
	<i>Amphora</i> sp.	
	<i>Amphora tenuistriata</i>	Mang. in Bourr. & Mang.
	<i>Anomoeoneis vitrea</i>	(Grun.) Patr. & Reim.
	<i>Asterionella formosa</i>	Hass.
	<i>Caloneis bacillaris</i> v. <i>thermalis</i> ?	
	<i>Caloneis bacillum</i>	(Grun.) Cl.
	<i>Caloneis hyalina</i>	Hust.
	<i>Caloneis ventricosa</i> v. <i>minuta</i>	(Grun.) Mills
	<i>Cocconeis diminuta</i>	Pant.
	<i>Cocconeis pediculus</i>	Ehr.
	<i>Cocconeis placentula</i>	Ehr.
	<i>Cocconeis placentula</i> v. <i>euglypta</i>	(Ehr.) Cl.
	<i>Cocconeis placentula</i> v. <i>lineata</i>	(Ehr.) Cl.
	<i>Cocconeis</i> sp.	
	<i>Coscinodiscus lacustris</i>	Grun.
	<i>Cyclotella antiqua</i> ?	W. Sm.
	<i>Cyclotella atomus</i>	Pant.
	<i>Cyclotella atomus</i> ?	Pant.
	<i>Cyclotella comensis</i>	Grun.
	<i>Cyclotella comensis</i> v. 1	
	<i>Cyclotella comensis</i> v. 2	
	<i>Cyclotella comta</i>	(Ehr.) Kutz.
	<i>Cyclotella comta</i> v. <i>oligactis</i>	(Ehr.) Grun.
	<i>Cyclotella cryptica</i>	Reim. et al.
	<i>Cyclotella gamma</i>	Sov.
	<i>Cyclotella kuetzingiana</i>	Thw.
	<i>Cyclotella kuetzingiana</i> v. <i>planetophora</i>	Fricke
	<i>Cyclotella kuetzingiana</i> v. <i>planetophora</i> ?	Fricke
	<i>Cyclotella meneghiniana</i>	Kutz.
	<i>Cyclotella michiganiana</i>	Skv.
	<i>Cyclotella ocellata</i>	Pant.

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Cyclotella operculata</i>	(Ag.) Kutz.
	<i>Cyclotella pseudostelligera</i>	Hust.
	<i>Cyclotella</i> sp.	
	<i>Cyclotella</i> sp. #1	
	<i>Cyclotella stelligera</i>	(Cl. & Grun.) V.H.
	<i>Cyclotella wolterecki</i>	Hust.
	<i>Cymatopleura solea</i>	(Breb. & Godey) W. Sm.
	<i>Cymatopleura solea</i> v. <i>apiculata</i>	(W. Sm.) Ralfs
	<i>Cymbella affinis</i>	Kutz.
	<i>Cymbella microcephala</i>	Grun.
	<i>Cymbella minuta</i>	Hilse
	<i>Cymbella minuta</i> v. <i>silesiaca</i>	(Bleisch) Reim.
	<i>Cymbella prostrata</i> v. <i>auerswaldii</i>	(Rabh.) Reim.
	<i>Cymbella pusilla</i>	Grun.
	<i>Cymbella</i> sp.	
	<i>Denticula tenuis</i> v. <i>crassula</i>	(Nag.) W. & G.S. West.
	<i>Diatoma anceps</i>	(Ehr.) Kirchn.
	<i>Diatoma tenue</i> v. <i>elongatum</i>	Lyngb.
	<i>Diatoma vulgare</i>	Bory
	<i>Diploneis oculata</i>	(Breb.) Cl.
	<i>Entomonels ornata</i>	(J.W. Ball.) Reim.
	<i>Fragilaria brevistriata</i>	Grun.
	<i>Fragilaria brevistriata</i> v. <i>inflata</i>	(Pant.) Hust.
	<i>Fragilaria capucina</i>	Desm.
	<i>Fragilaria construens</i>	(Ehr.) Grun.
	<i>Fragilaria construens</i> v. <i>minuta</i>	Temp. & Per.
	<i>Fragilaria construens</i> v. <i>pumila</i>	Grun.
	<i>Fragilaria construens</i> v. <i>venter</i>	(Ehr.) Grun.
	<i>Fragilaria crotonensis</i>	Kitton
	<i>Fragilaria intermedia</i> v. <i>fallax</i>	(Grun.) Stoerm. & Yang
	<i>Fragilaria leptostauron</i>	(Ehr.) Hust.
	<i>Fragilaria leptostauron</i> v. <i>dubia</i>	(Grun.) Hust.
	<i>Fragilaria nitzschoides</i>	Grun.
	<i>Fragilaria pinnata</i>	Ehr.
	<i>Fragilaria pinnata</i> v. <i>lanceolata</i>	(Schum.) Hust.
	<i>Fragilaria pinnata</i> v. <i>pinnata</i>	
	<i>Fragilaria</i> sp.	
	<i>Fragilaria vaucheriae</i>	(Kutz.) Peters.
	<i>Gomphonema clevei</i>	Fricke
	<i>Gomphonema dichotomum</i>	Kutz.
	<i>Gomphonema parvulum</i>	Kutz.
	<i>Gomphonema</i> sp.	
	<i>Gomphonema tergestinum</i>	(Grun.) Fricke
	<i>Gyrosigma attenuatum</i>	(Kutz.) Rabh.
	<i>Gyrosigma sciaticum</i>	(Sulliv. & Wormley) Cl.
	<i>Melosira agassizii</i> v. <i>malayensis</i>	Ostenf.
	<i>Melosira distans</i>	(Ehr.) Kutz.
	<i>Melosira distans</i> v. <i>limnetica</i>	O. Mull.
	<i>Melosira granulata</i>	(Ehr.) Ralfs
	<i>Melosira granulata</i> v. <i>angustissima</i>	O. Mull.
	<i>Melosira granulata?</i>	(Ehr.) Ralfs
	<i>Melosira islandica</i>	O. Mull.

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Melosira italica</i> subsp. subarctica	O. Mull.
	<i>Melosira</i> sp.	
	<i>Navicula acceptata</i>	Hust.
	<i>Navicula anglica</i>	Ralfs
	<i>Navicula capitata</i>	Ehr.
	<i>Navicula capitata</i> v. <i>hurgarica</i>	(Grun.) Ross
	<i>Navicula capitata</i> v. <i>luneburgensis</i>	(Grun.) Patr.
	<i>Navicula cincta</i>	(Ehr.) Ralfs
	<i>Navicula cocconeiformis</i>	Greg.
	<i>Navicula cryptocephala</i>	Kutz.
	<i>Navicula cryptocephala</i> v. <i>veneta</i>	(Kutz.) Rabh.
	<i>Navicula exigua</i>	Greg. ex Grun.
	<i>Navicula exigua</i> v. <i>capitata</i>	Patr.
	<i>Navicula lanceolata</i>	(Ag.) Kutz.
	<i>Navicula menisculus</i>	Schum.
	<i>Navicula menisculus</i> v. <i>upsaliensis</i>	(Grun.) Grun.
	<i>Navicula minima</i>	Grun.
	<i>Navicula pseudoscutiformis</i>	Hust.
	<i>Navicula pupula</i>	Kutz.
	<i>Navicula radiosa</i> v. <i>tenella</i>	(Breb.) Cl. & Moll.
	<i>Navicula salinarum</i> v. <i>intermedia</i>	(Grun.) Cl.
	<i>Navicula seminulcides</i>	Hust.
	<i>Navicula seminulum</i>	Grun.
	<i>Navicula</i> sp.	
	<i>Navicula stroemii</i>	Hust.
	<i>Navicula terminata</i>	Hust.
	<i>Navicula tripunctata</i>	(O.F.Mull.) Bory
	<i>Navicula viridula</i> v. <i>rostellata</i>	(Kutz.) Cl.
	<i>Navicula vitabunda</i>	Hust.
	<i>Navicula zanoni</i>	Hust.
	<i>Neidium affine</i>	Pfitz.
	<i>Nitzschia acicularioides</i>	Arch. non Hust.
	<i>Nitzschia acicularis</i>	(Kutz.) W. Sm.
	<i>Nitzschia acicularis?</i>	(Kutz.) W. Sm.
	<i>Nitzschia acula</i>	Hantz. ex Cl. & Grun.
	<i>Nitzschia amphibia</i>	Grun.
	<i>Nitzschia angustata</i>	(W. Sm.) Grun.
	<i>Nitzschia angustata</i> v. <i>acuta</i>	Grun.
	<i>Nitzschia apiculata</i>	(Greb.) Grun.
	<i>Nitzschia archbaldii</i>	L.-B.
	<i>Nitzschia closterium</i>	(Ehr.) W. Sm.
	<i>Nitzschia confinis</i>	Hust.
	<i>Nitzschia dissipata</i>	(Kutz.) Grun.
	<i>Nitzschia dissipata</i> v. <i>media</i>	(Hantz.) Grun.
	<i>Nitzschia fonticola</i>	Grun.
	<i>Nitzschia frustulum</i>	(Kutz.) Grun.
	<i>Nitzschia gancersheimiensis</i>	Krasske
	<i>Nitzschia gracilis</i>	Hantz.
	<i>Nitzschia hantzschiana</i>	Rabh.
	<i>Nitzschia inconspicua</i>	Grun.
	<i>Nitzschia intermedia</i>	Hantz.
	<i>Nitzschia kuetzingiana</i>	Hilse

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	<i>Nitzschia kuetzingioides?</i>	Hust.
	<i>Nitzschia lauerburgiana</i>	W. Sm.
	<i>Nitzschia linearis</i>	(Kutz.) W. Sm.
	<i>Nitzschia palea</i>	(Kutz.) Grun.
	<i>Nitzschia palea</i> v. <i>debilis</i>	Grun.
	<i>Nitzschia palea</i> v. <i>tenuirostris</i>	Grun.
	<i>Nitzschia paleacea</i>	Hust.
	<i>Nitzschia pumila</i>	Hust.
	<i>Nitzschia pura</i>	(Kutz.) Grun. em. L.-B.
	<i>Nitzschia pusilla</i>	Hantz.
	<i>Nitzschia recta</i>	Grun.
	<i>Nitzschia romana</i>	Hust.
	<i>Nitzschia rostellata</i>	Hust.
	<i>Nitzschia sociabilis</i>	Hust.
	<i>Nitzschia</i> sp.	Hust.
	<i>Nitzschia spiculoides</i>	Hust.
	<i>Nitzschia subacicularis</i>	Hust.
	<i>Nitzschia sublinearis</i>	W. Sm.
	<i>Nitzschia tenuis</i>	Hust.
	<i>Nitzschia tropica</i>	(Arnott) A. Mayer
	<i>Nitzschia tryblionella</i>	Grun.
	<i>Nitzschia tryblionella</i> v. <i>debilis</i>	Grun.
	<i>Nitzschia tryblionella</i> v. <i>victoriae</i>	H.L. Sm.
	<i>Nitzschia tryblionella</i> v. <i>victoriae?</i>	Zach.
	<i>Rhizosolenia eriensis</i>	(Weber) Hasle & Evens.
	<i>Rhizosolenia longiseta</i>	Patr.
	<i>Rhizosolenia</i> sp.	Hust.
	<i>Skeletonema pectus</i>	Hust.
	<i>Stauroneis kriegeri</i>	(Kutz.) Krieg.
	<i>Stephanodiscus alpinus</i>	Grun.
	<i>Stephanodiscus alpinus</i> - auxospore	Grun.
	<i>Stephanodiscus alpinus?</i>	
	<i>Stephanodiscus binderanus</i>	
	<i>Stephanodiscus hantzschii</i>	
	<i>Stephanodiscus minutus</i>	
	<i>Stephanodiscus minutus</i> - auxospore	
	<i>Stephanodiscus niagarae</i>	Ehr.
	<i>Stephanodiscus niagarae</i> - auxospore	
	<i>Stephanodiscus niagarae</i> v. <i>magnifica</i>	Fricke
	<i>Stephanodiscus</i> sp.	
	<i>Stephanodiscus</i> sp. #03	
	<i>Stephanodiscus</i> sp. #04	
	<i>Stephanodiscus</i> sp. #07	
	<i>Stephanodiscus</i> sp. -auxospore	
	<i>Stephanodiscus tenuis</i>	Hust.
	<i>Stephanodiscus tenuis</i> v. #01	
	<i>Stephanodiscus tenuis</i> v. #02	
	<i>Stephanodiscus tenuis?</i>	Hust.
	<i>Surirella birostrata</i>	Hust.
	<i>Surirella ovata</i>	Kutz.
	<i>Surirella ovata</i> v. <i>pinnata</i>	(W. Sm.) Hust.
	<i>Surirella ovata</i> v. <i>salina</i>	(W. Sm.) Hust.

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
BAC	Surirella sp.	
	Surirella turgida	W. Sm.
	Synedra acus?	Kutz.
	Synedra amphicephala v. austica	(Grun.) Hust.
	Synedra delicatissima	W. Sm.
	Synedra delicatissima v. angustissima	Grun.
	Synedra filiformis	Grun.
	Synedra filiformis v. exilis	A. Cl.
	Synedra miniscula	Grun.
	Synedra parasitica	W. Sm.
	Synedra ulna v. longissima	(W. Sm.) Brun.
	Tabellaria fenestrata	Kutz.
	Tabellaria fenestrata v. geniculata	A. Cl.
	Tabellaria flocculosa	(Roth) Kutz.
	Tabellaria flocculosa v. linearis	Koppen
	Tabellaria sp.	
	Thalassiosira fluviatilis	Hust.
CAT	Vacuolaria sp.	
CHL	Actinastrum gracilimum	G.M. Smith
	Ankistrodesmus sp. #02	
	Ankyra judayi	(G.M. Sm.) Fott
	Carteria sp.	
	Carteria sp. -cvoid	
	Carteria sp. -sphere	
	Chlamydocapsa planktonica	(W. & G.S. West) Fott
	Chlamydocapsa sp.	
	Chlamydomonas sp.	
	Chlamydomonas sp. - ovoid	
	Chlamydomonas sp. - sphere	
	Chlorogonium minimum	Playf.
	Chlorogonium sp.	
	Closterium aciculare	T. West
	Closterium parvulum	Nag.
	Closterium sp.	
	Coelastrum cambricum	Arch.
	Coelastrum microporum	Nag. in A. Braun
	Coelastrum sp.	
	Cosmarium sp.	
	Crucigenia irregularis	Wille
	Crucigenia quadrata	Morren
	Crucigenia rectangularis	A. Braun
	Crucigenia tetrapedia	(Kirch.) W. & G.S. West
	Dictyosphaerium ehrenbergianum	Nag.
	Dictyosphaerium pulchellum	Wood.
	Elakatothrix gelatinosa	Wille
	Elakatothrix viridis	(Snow) Printz
	Eudorina elegans	Ehr.
	Franceia ovalis	(France) Lemm.
	Golenkinia radiata	(Chod.) Wille
	Green Filament	

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHL	Green coccoid #04	
	Green coccoid - acicular	
	Green coccoid - bacilliiform	
	Green coccoid - bicells	
	Green coccoid - fusiform bicells	
	Green coccoid - oval	
	Green coccoid - ovoid	
	Green coccoid - sphere	
	Green flagellate - sphere	
	Kirchneriella contorta	(Schmid.) Bohm
	Kirchneriella obesa	(W. West) Schmidle
	Lagerheimia balatonica	(Scherff. in Kol) Hind.
	Lagerheimia ciliata	(Lagerh.) Chod.
	Lagerheimia genevensis	(Chod.) Chod.
	Lagerheimia longiseta v. major	G.M. Sm.
	Lagerheimia quadriseta	(Lemm.) G.M. Sm.
	Lagerheimia sp.	
	Lagerheimia subsalsa	Lemm.
	Lobomonas sp.?	
	Micractinium pusillum	Fresenius
	Monoraphidium contortum	(Thur.) Kom.-Legn.
	Monoraphidium griffithii	(Berkel.) Kom.-Legn.
	Monoraphidium irregulare	(G.M. Sm.) Kom.-Legn.
	Monoraphidium minutum	(Nag.) Kom.-Legn.
	Mougeotia sp.	
	Nephrocytium Agardhianum	Nag.
	Nephrocytium limneticum	(G.M. Sm.) G.M. Sm.
	Nephrocytium limneticum?	(G.M. Sm.) G.M. Sm.
	Oedogonium sp.	
	Oocystis sp.	
	Oocystis sp. #1	
	Oocystis sp.?	
	Oocystis borgei	Snow
	Oocystis crassa	Wittr. in Wittr. & Nord.
	Oocystis elliptica v. minor	W. West
	Oocystis lacustris	Chod.
	Oocystis marschii	Lemm.
	Oocystis parva	West & West
	Oocystis pusilla	Hansg.
	Oocystis solitaria	Wittr. in Wittr. & Nord.
	Oocystis submarina	Lagerh.
	Pandorina morum?	(Muell.) Bory
	Paradoxia multiseta	Swir.
	Pediastrum boryanum	(Turp.) Menegh.
	Pediastrum duplex v. clathratum	(A. Braun) Lagerh.
	Pediastrum duplex v. reticulatum	Lagerh.
	Pediastrum simplex	(Meyen) Lemm.
	Pediastrum simplex v. duodenarium	(Bail.) Rabh.
	Pediastrum sp.	
	Scenedesmus abundans	(Kirch.) Chod.
	Scenedesmus acuminatus	(Lagerh.) Chod.
	Scenedesmus arcuatus	Lemm.



## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHL	<i>Scenedesmus armatus</i>	(Chod.) G.M. Sm.
	<i>Scenedesmus bicaudatus</i>	(Hansg.) Chod.
	<i>Scenedesmus carinatus</i>	(Lemm.) Chod.
	<i>Scenedesmus denticulatus</i>	Lagerh.
	<i>Scenedesmus eccrnis</i>	(Ralfs) Chod.
	<i>Scenedesmus intermedius</i>	Chod.
	<i>Scenedesmus intermedius</i> v. <i>bicaudatus</i>	Hortob.
	<i>Scenedesmus quadricauda</i>	(Turp.) Breb.
	<i>Scenedesmus securiformis</i>	Playf.
	<i>Scenedesmus</i> sp.	
	<i>Scenedesmus spinosus</i>	Chod.
	<i>Scenedesmus spinosus?</i>	Chod.
	<i>Schroederia setigera</i>	(Schroed.) Lemm.
	<i>Sphaerello cystis lateralis</i>	Fott & Novak.
	<i>Sphaerellopsis</i> sp.	
	<i>Sphaerocystis schroeteri</i>	Chod.
	<i>Staurostrum paradoxum</i>	Meyen
	<i>Staurostrum</i> sp.	
	<i>Stichococcus</i> sp.	
	<i>Tetraedron caudatum</i>	(Corda) Hansg.
	<i>Tetraedron minimum</i>	(A. Braun) Hansg.
	<i>Tetraedron muticum</i>	(A. Braun) Hansg.
	<i>Tetraedron regulare</i> v. <i>incus</i>	Teilung
	<i>Tetraspora lacustris</i>	Lemm.
	<i>Tetrastrum heteracanthum</i>	(Nordst.) Chod.
	<i>Tetrastrum staurogeniaeforme</i>	(Schroed.) Lemm.
	<i>Treubaria planktonica</i>	(G.M. Sm.) Korch.
	<i>Treubaria setigera</i>	(Arch.) G.M. Sm.
	<i>Treubaria</i> sp.	
CHR	<i>Bitrichia chodatii</i>	(Rev.) Chod.
	<i>Chrysolykos planktonicus</i>	Mack.
	<i>Chrysolykos skuja</i>	(Nauw.) Bourr.
	<i>Chrysosphaerella longispina</i>	Laut. em. Nich.
	<i>Dinobryon acuminatum</i>	Rutt.
	<i>Dinobryon bavaricum</i>	Imhof
	<i>Dinobryon cylindricum</i>	Imhof
	<i>Dinobryon divergens</i>	Imhof
	<i>Dinobryon sertularia</i>	Ehr.
	<i>Dinobryon sociale</i> v. <i>americanum</i>	(Brunnth.) Bachm.
	<i>Dinobryon</i> sp.	
	<i>Dinobryon stokesii</i> v. <i>epiplanktonicum</i>	Skuja
	<i>Dinobryon utriculus</i> v. <i>tabellariae</i>	Lemm.
	<i>Haptophyte</i> sp.	
	<i>Kephyrion cupuliformae</i>	Conr.
	<i>Kephyrion</i> sp. #1 - <i>Pseudokephyrion entzii</i>	
	<i>Kephyrion</i> sp. #2	
	<i>Kephyrion</i> sp. #3	
	<i>Mallomonas</i> sp.	
	<i>Ochromonas</i> sp.	
	<i>Ochromonas</i> sp. - ovoid	
	<i>Paraphysomonas</i> sp.?	

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CHR	<i>Pseudokephyrion millerense</i>	Nich.
	<i>Pseudokephyrion</i> sp. #1	
	<i>Pseudotetraedron neglectum</i>	Pasch.
	Unidentified coccoids	
	Unidentified flagellate	
	Unidentified loricate - ovoid	
	Unidentified loricate - sphere	
COL	<i>Bicoeca campanulata</i>	(Lack.) Bourr. em. Skuja
	<i>Bicoeca crystallina</i>	Skuja
	<i>Bicoeca</i> sp.	
	<i>Bicoeca</i> sp. #01	
	<i>Bicoeca</i> sp. #04	
	<i>Bicoeca</i> sp. #05	
	<i>Bicoeca tubiformis</i>	Skuja
	<i>Codonosiga</i> sp.	
	Colorless flagellates	
	Colorless flagellates - colonial	
	<i>Monosiga ovata</i>	Kent
	<i>Salpingoeca amphorae</i>	Kent
	<i>Salpingoeca gracilis</i>	Clark
	<i>Stelexmonas dichotoma</i>	Lack.
	<i>Stylothea aurea</i>	(Bachm.) Boloch.
CRY	<i>Chroomonas acuta</i>	Uterm.
	<i>Chroomonas norstedtii</i>	Hansg.
	<i>Cryptomonas</i> - cyst	
	<i>Cryptomonas caloata</i>	Schill.
	<i>Cryptomonas curvata</i>	Ehr.
	<i>Cryptomonas curvata?</i>	Ehr.
	<i>Cryptomonas ercsa</i>	Ehr.
	<i>Cryptomonas ercsa</i> v. <i>reflexa</i>	Marss.
	<i>Cryptomonas marssonii</i>	Skuja
	<i>Cryptomonas marssonii</i> v.?	Skuja
	<i>Cryptomonas ovata</i>	Ehr.
	<i>Cryptomonas phaseolus</i>	Skuja
	<i>Cryptomonas pyrenoidifera</i>	Geitl.
	<i>Cryptomonas reflexa</i>	Skuja
	<i>Cryptomonas rostratiformis</i>	Skuja
	<i>Cryptomonas rostratiformis?</i>	Skuja
	<i>Cryptomonas</i> sp.	
	<i>Rhodomonas lens</i>	Pasch. & Rutt.
	<i>Rhodomonas minuta</i>	Skuja
	<i>Rhodomonas minuta</i> v. <i>nannoplanktica</i>	Skuja
CYA	<i>Agmenellum quadruplicatum</i>	(Menegh.) Breb.
	<i>Anabaena</i> sp.	
	<i>Anabaena spiracles</i>	Kleb.
	<i>Anacystis marina</i>	(Hansg.) Dr. & Daily
	<i>Anacystis montana</i> v. <i>minor</i>	Dr. & Daily
	<i>Anacystis thermalis</i>	(Menegh.) Dr. & Daily
	<i>Anacystis thermalis</i> f. <i>major</i>	(Lagerh.) Dr. & Daily

## SPECIES LIST - LAKE ERIE PHYTOPLANKTON (1983)

DIV	TAXON	AUTHORITY
CYA	Aphanizomenon flos-aquae	(L.) Ralfs
	Coccochloris elabans	Dr. & Daily
	Coccochloris penlocystis	(Kutz.) Dr. & Daily
	Coelosphaerium dubium	Grun. in Rabh.
	Coelosphaerium naegelianum	Unger
	Gomphosphaeria lacustris	Chod.
	Merismopedia tenuissima	Lemm.
	Oscillatoria limnetica	Lemm.
	Oscillatoria subbrevis	Schmid.
	Oscillatoria tenuis	C.A. Ag.
	Oscillatoria tenuis?	C.A. Ag.
EUG	Euglena sp.	
	Trachelomonas sp.	
PYR	Amphidinium sp.	
	Ceratium hirundinella	(O.F.Mull.) Schrank
	Ceratium hirundinella - cyst	(O.F.Mull.) Schrank
	Gymnodinium sp.	
	Gymnodinium sp. #2	
	Gymnodinium sp. #3	
	Peridinium aciculiferum	Lemm.
	Peridinium aciculiferum?	Lemm.
	Peridinium inconspicuum	Lemm.
UNI	Peridinium sp.	
	Unidentified flagellate #01	
	Unidentified flagellate - ovoid	
	Unidentified flagellate - spherical	

## Table D

Zooplankton Species List: Lake Michigan

GREAT LAKES ZOOPLANKTON SPECIES LIST  
LAKE MICHIGAN  
(1983)

DIVISION	TAXON
Calanoida	Calanoid - copepodite Diaptomus ashlandi Diaptomus minutus Diaptomus oregonensis Diaptomus sicilis Diaptomus siciloides Epischura lacustris Eurytemora affinis Limnocalanus macrurus Senecella calanoides
Cladocera	Alona affinis Bosmina longirostris Camptocercus rectirostris Ceriodaphnia lacustris Chydoridae Chydorus sphaericus Daphnia catawba Daphnia dubia Daphnia galaeta mendota Daphnia immatures Daphnia longiremis Daphnia middendorffiana Daphnia pulicaria Daphnia retrocurva Daphnia schodleri Daphnia sp. Diaphanosoma leuchtenbergianum Eubosmina coregoni Eurycercus lamellatus Holopedium gibberum Ilyocryptus spinifer Leptodora kindtii Polyphemus pediculus
Copepoda	Copepoda Nauplii
Cyclopoida	Cyclopoid - copepodite Cyclops bicuspidatus thomasi Eucyclops prionophorus Mesocyclops edax Tropocyclops prasinus mexicanus
Harpacticoida	Harpacticoida
Mysidacea	Mysis relicta
Rotifera	Ascomorpha sp. Asplanchna priodonta Brachionus quadridentatus

GREAT LAKES ZOOPLANKTON SPECIES LIST  
LAKE MICHIGAN  
(1983)

## DIVISION

## TAXON

## Rotifera

Cephalodella sp.  
Collotheca sp.  
Conochilcides sp.  
Conochilus unicornis  
Encentrum sp.  
Euchlanis sp.  
Filina longiseta  
Gastropus stylifer  
Kellicottia longispina  
Keratella cochlearis  
Keratella crassa  
Keratella earlinae  
Keratella hiemalis  
Keratella quadrata  
Lecane tenuiseta  
Monostyla sp.  
Notholca acuminata  
Notholca foliacea  
Notholca laurentiae  
Notholca squamula  
Notholca striata  
Ploesoma sp.  
Polyarthra dolichoptera  
Polyarthra major  
Polyarthra remata  
Polyarthra vulgaris  
Synchaeta sp.  
Trichocerca cylindrica  
Trichocerca multicornis  
Trichocerca sp.

## Table E

Zooplankton Species List: Lake Huron

GREAT LAKES ZOOPLANKTON SPECIES LIST  
LAKE HURON  
(1983)

DIVISION	TAXON
Calanoida	Calanoid - copepodite Diaptomus ashlandi Diaptomus minutus Diaptomus oregonensis Diaptomus sicilis Diaptomus sicilloides Epischura lacustris Limnocalanus macrurus Senecella calanoides
Cladocera	Bosmina longirostris Daphnia catawba Daphnia dubia Daphnia galaeta mendota Daphnia pulicaria Daphnia retrocurva Daphnia schodleri Daphnia sp. Diaphanosoma leuchtenbergianum Diaphanosoma sp. Eubosmina coregoni Holopedium gibberum Leptodora kindtii Polyphemus pediculus Sida crystallina
Copepoda	Copepoda Nauplii
Cyclopoida	Cyclopoid - copepodite Cyclops bicuspidatus thomasi Cyclops vernalis Mesocyclops edax Tropocyclops prasinus mexicanus
Mysidacea	Mysis relicta
Rotifera	Ascomorpha sp. Asplanchna priodonta Cephalodella sp. Collotheca sp. Conochilus unicornis Euchlanis sp. Filina longiseta Gastropus sp. Gastropus stylifer Kelllicottia longispina Keratella cochlearis Keratella cochlearis hispida Keratella crassa Keratella earlinae



GREAT LAKES ZOOPLANKTON SPECIES LIST  
LAKE HURON  
(1983)

DIVISION	TAXON
Rotifera	Keratella hiemalis
	Keratella quadrata
	Monostyla lunaris
	Notholca foliacea
	Notholca laurentiae
	Notholca squamula
	Ploesoma sp.
	Polyarthra dolichoptera
	Polyarthra major
	Polyarthra remata
	Polyarthra vulgaris
	Rotifer - soft body
	Synchaeta sp.
	Trichocerca cylindrica
	Trichocerca multiepinis
	Trichocerca sp.
	Trichotria pocillum

**Table F****Zooplankton Species List: Lake Erie**

**TECHNICAL REPORT DATA**  
(Please read instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES Paul Bertram, Project Officer					
16. ABSTRACT  During the spring, summer and autumn of 1984 and winter of 1985, the structure of the plankton community in the offshore waters of Lakes Erie, Huron and Michigan was monitored. By examining changes in the phytoplankton and zooplankton in relation to water chemistry, evidence was found suggesting little change in the trophic status of Lake Huron and Michigan while an improvement in the trophic status of Lake Erie was evident over the past several years. The offshore region of Lake Michigan is experiencing changes in phytoplankton and zooplankton composition consistent with nutrient control and top-down control by fish. Even so, the biomass of phytoplankton and zooplankton and the trophic status of the lake have not changed significantly. The appearance and establishment of <u>Daphnia pulicaria</u> in offshore waters of Lake Huron suggest a change in the forage fish base. With the exception of the resurgence of <u>Asterionella formosa</u> in Lake Erie, plankton composition has changed little since the 1960's. However, dramatic reductions in biomass of nuisance and eutrophic indicator species have occurred. These changes are consistent with expectations of long-term nutrient control. However, a change in piscivory is evident that has apparently allowed the establishment of the large caldoceran <u>Daphnia pulicaria</u> .					
17. KEY WORDS AND DOCUMENT ANALYSIS					
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